TECHNICAL THEORY
FOR SERVICING

# DISCMAN
# POWER SUPPLY CIRCUIT
# OPERATION MANUAL

[photo: D-E705]

COMPACT DISC
COMPACT PLAYER

SONY®

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# 1. POWER SUPPLY CIRCUIT CORRESPONDENCE TABLE

Table 1-1 shows the power supply circuit correspondence table. This new technical theory for servicing shows the power supply block diagrams of the following models among the respective power supply circuit series.

- D-E705 series power supply system → D-E705
- D-365 series power supply system → D-365
- D-245 series power supply system → D-245

However, among the D-245 series models, those that do not have the ESP circuit do not have the D-RAM IC drive voltage generator circuit which is described here in chapter "4. OPERATION OF THE D-245 SERIES POWER SUPPLY CIRCUIT."

Table 1-1 Power supply circuit correspondence table

| Power supply circuit series | Model names | Reference pages |
|---|---|---|
| D-E705 series | D-E700/E800 | pages 3 to 25 |
| | D-E705/E805 | |
| D-365 series | D-263/265 | pages 26 to 35 |
| | D-365/375/368/369CK | |
| | D-465/475 | |
| | D-E500/E504 | |
| D-245 series | D-140/141/143/141CK/142CK/144K/145/147CR/148CR | pages 36 to 47 |
| | D-150AN/151/151C/151V/152CK/152CKT/153/155 | |
| | D-162CKC/162CKT | |
| | D-240/247/242CK/242SK/242CKT/243CK/245 | |
| | D-330/340/345 | |
| | D-451SP | |
| | D-835K/837K/838K/840K/842K/844K/848K | |

# 2. OPERATION OF THE D-E705 SERIES POWER SUPPLY CIRCUIT

## 2-1. Types of Power Supply

The D-E705 series compact CD player can be operated on the following three types of power supply.

- ♦ DC power supply
  - • AC adapter ..... 4.5 V (supplied)

- ♦ Battery
  - • Dry cell battery (size AA, 2 pcs)..... 3.0 V (optional), or
  - • Rechargeable nickel-hydrogen battery (NH-DM2AA)..... 2.4 V (supplied)

## 2-2. Identifying the Power Supplies

When the system controller IC801 is started up, it identifies from where the main power voltage is supplied. It also stops operation if batteries that do not satisfy the specifications are used. The system controller IC identifies the power supplies from the following three detections.

(1) Pin ⑤⑦[DCINMNT] : The voltage that is obtained by dividing the DCIN input voltage by the resistors.

(2) Pin ⑤⑧[BATMNT] : The voltage that is obtained by dividing the battery terminal voltage by the resistors.

(3) Pin ⑥①[CHGMNT2] : The voltage from the rechargeable battery detection terminal ("H": When the supplied rechargeable battery is inserted)

Table 2-1 Power supply identification table

| | | Pin ⑤⑦[DCINMNT] | Pin ⑤⑧[BATMNT] | Pin ⑥①[CHGMNT2] |
|---|---|---|---|---|
| DC supply (from AC adapter) | | H | H | L (H*2-1) |
| Battery | Rechargeable battery | L | H | H |
| | Dry cell battery | L | H | L |

* 2-1: When a rechargeable battery is inserted, the input of Pin ⑥①[CHGMNT2] goes high.

## 2-3. Circuit Voltage

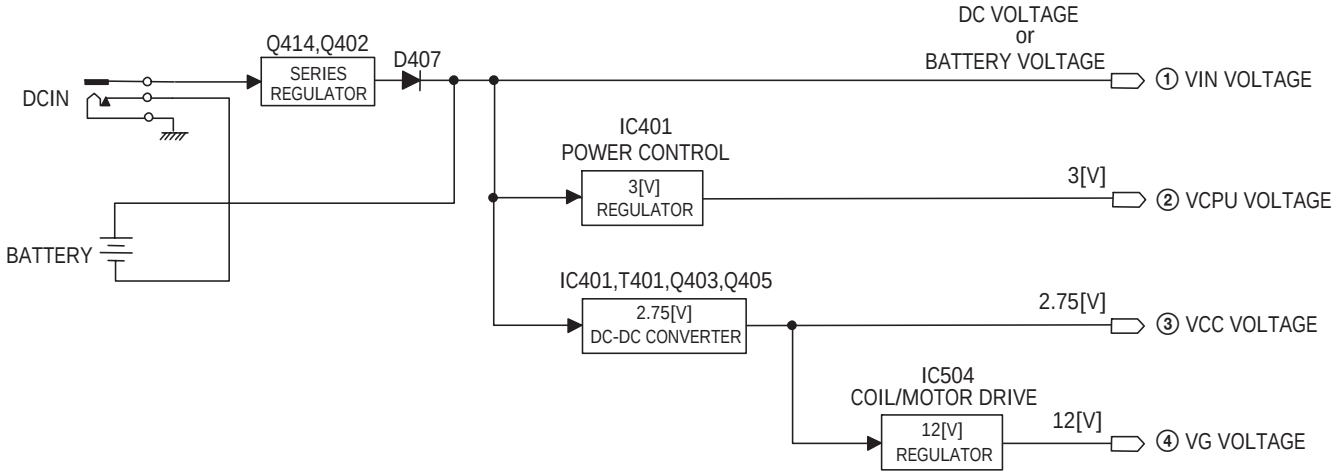



Fig. 2-1 Power supply voltage generation block diagram

During AC adaptor drive operation, the following four outputs of the power supply voltage are generated. (Refer to Fig. 2-1.)

① VIN voltage

- The external voltage input to the DC jack is regulated by the SERIES REGULATOR (Q414, Q402), passed through D407 and output as the VIN voltage (approx. 4.5 V).
- When the Discman is operated on battery, the battery terminal voltage is supplied as the VIN voltage.

② VCPU voltage → "POWER CONTROL IC401"

- This voltage is used for driving the system controller IC801, and is 3.0 V.

③ VCC voltage → "2.75 V DC-DC CONVERTER (POWER CONTROL IC401, T401, Q403, Q405, etc.)"

- This voltage is used by the RF AMP IC501, DIGITAL SIGNAL PROCESSOR IC502, COIL/MOTOR DRIVE IC504, etc., and is 2.75 V.

④ VG voltage → "COIL/MOTOR DRIVE IC504"

- This voltage is used by the POWER CONTROL IC401, etc., and is approx. 12 V.

Generation of the respective voltages is described below.

### 1. Generation of VIN Voltage

When the DC plug of the AC adapter is connected to the DC jack, the input voltage is regulated by the SERIES REGULATOR (Q414 and Q402), passed through D407 and is output to the POWER CONTROL IC401 and others as the VIN voltage.

### 2. Generation of VCPU Voltage

The VCPU voltage generation circuit block diagram is shown in Fig. 2-2.

#### (1) AC adapter drive operation.

When the DC plug of the AC adapter is connected to the DC jack, the SERIES REGULATOR (Q414, Q402) is turned on and so the VIN voltage (approx. 4.5 V) is sent to pin㉚ [VIN] of the POWER CONTROL IC401 via D407, which starts up IC401. The VIN voltage is also sent to pin㉒ [VDO] of the POWER CONTROL IC401 via D404. As the POWER CONTROL IC401 is started up, the VCPU voltage 3.0 V is generated by the SERIES REGULATOR inside IC401. The VCPU voltage thus generated is sent from pin⑳ [VCPU] to pin① [VDD] and pin㊼ [VDD] of the system controller IC801 to start up the system controller IC801. The POWER CONTROL IC401 has a built-in step-up/step-down regulator, but the step-up circuit inside IC401 is not used in AC adapter drive mode because the voltage of 3.3 V or higher is input to pin㉒ [VDO] of IC401 all the time. (The switching waveform is not output from pin㉑ [SW] of IC401.)

#### (2) Battery drive operation

When the battery is inserted, the battery voltage is sent to pin㉚ [VIN] of the POWER CONTROL IC401 as the VIN voltage to start up IC401. As IC401 starts up, IC401 measures the input voltage at pin㉒ [VDO]. IC401 has a built-in VDO voltage detection circuit. If IC401 detects that the input voltage to pin㉒ [VDO] is less than 3.3 V, the PNM wave *2-2 is generated by the SYSTEM CONTROLLER section inside IC401 and so the switching waveform is output from pin㉑ [SW]. IC401 maintains the input voltage of pin㉒ [VDO] to 3.3V or higher by the self step-up circuit consisting of the switching output from pin㉑ [SW], L401, D404 and C439 at all times. On the other hand, the input voltage to pin㉒ [VDO] of the POWER CONTROL IC401 is sent to the SERIES REGULATOR inside IC401 to generate the VCPU voltage 3.0 V. The VCPU voltage thus generated is sent from pin⑳ [VCPU] to pin① [VDD] and pin㊼ [VDD] of the system controller IC801 to start up IC801. The step-up circuit inside IC401 operates only when a Discman is in the STOP mode. When a Discman is in a mode other than the STOP mode, the 2.75 V generator circuit, which is discussed later, starts operation and outputs the switching waveform from pin㉙ [VOUT2] of the POWER CONTROLLER IC401, so the input of pin② [IN] of the 4 V REGULATOR IC402 is kept to approx. 3.5 V or higher at all times by the step-up circuit consisting of the switching output from pin㉙ [VOUT2], Q403, T401, D406, and C418. The output of the step-up circuit changes in the range of approx. 3.5 V to 8 V depending on the conditions of load and power supply. The output voltage that is stepped up to 4 V or higher is input to the 4 V REGULATOR IC402 and is stepped down to 4 V by the SERIES REGULATOR inside IC402. The output voltage in the range of 3.5 V to 4 V is sent to pin㉒ [VDO] of the POWER CONTROL IC401 via D404 from pin③ [OUT] of IC402 which stops operation of the step-up circuit inside IC401.

*2-2: PNM (Pulse Number Modulation) wave
In the PNM wave, the pulse width is kept constant but the number of pulses is changed, whereas in the PWM wave, the duty ratio of the pulse is changed.

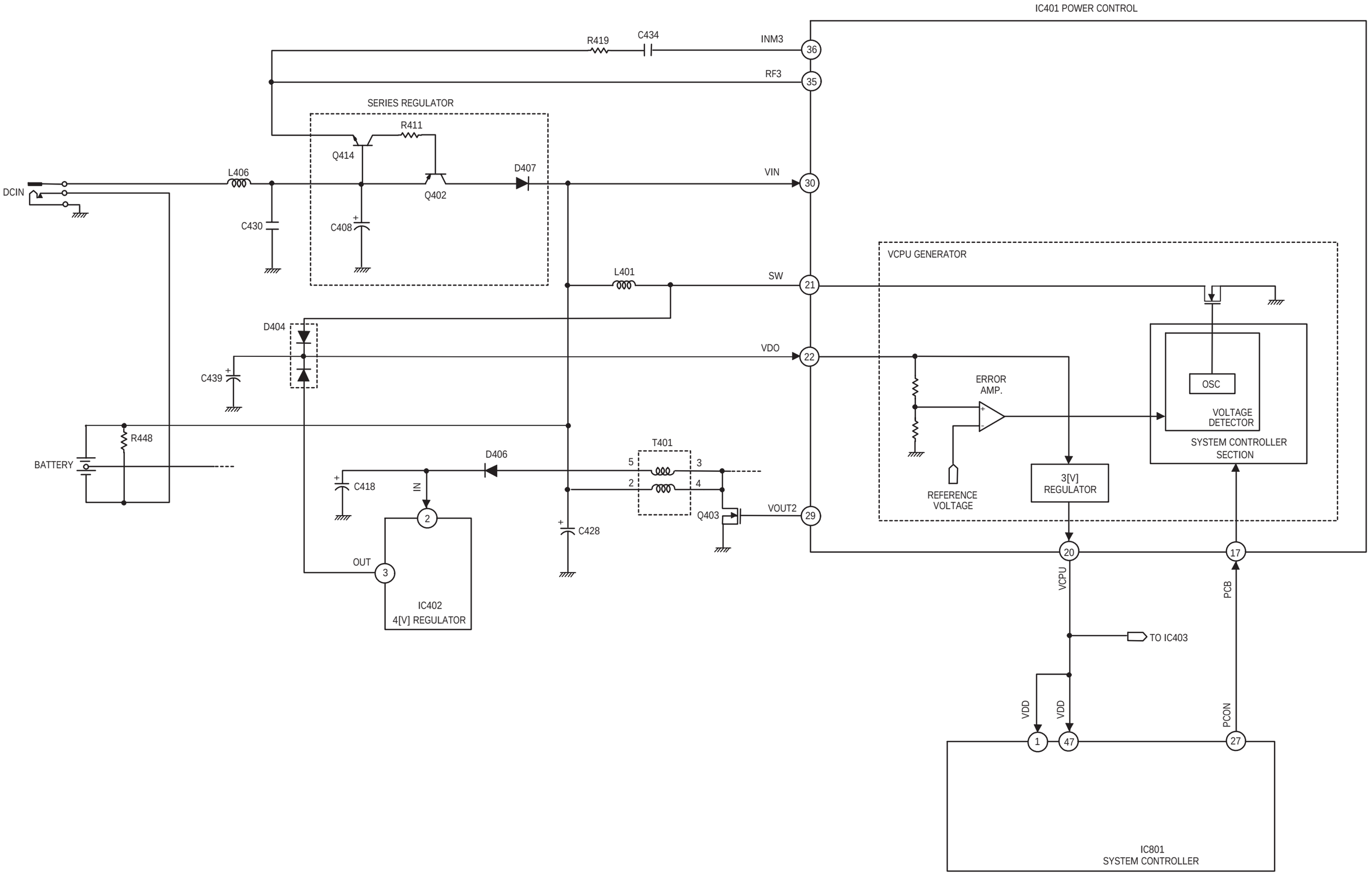



Fig. 2-2 VCPU voltage generation circuit block diagram

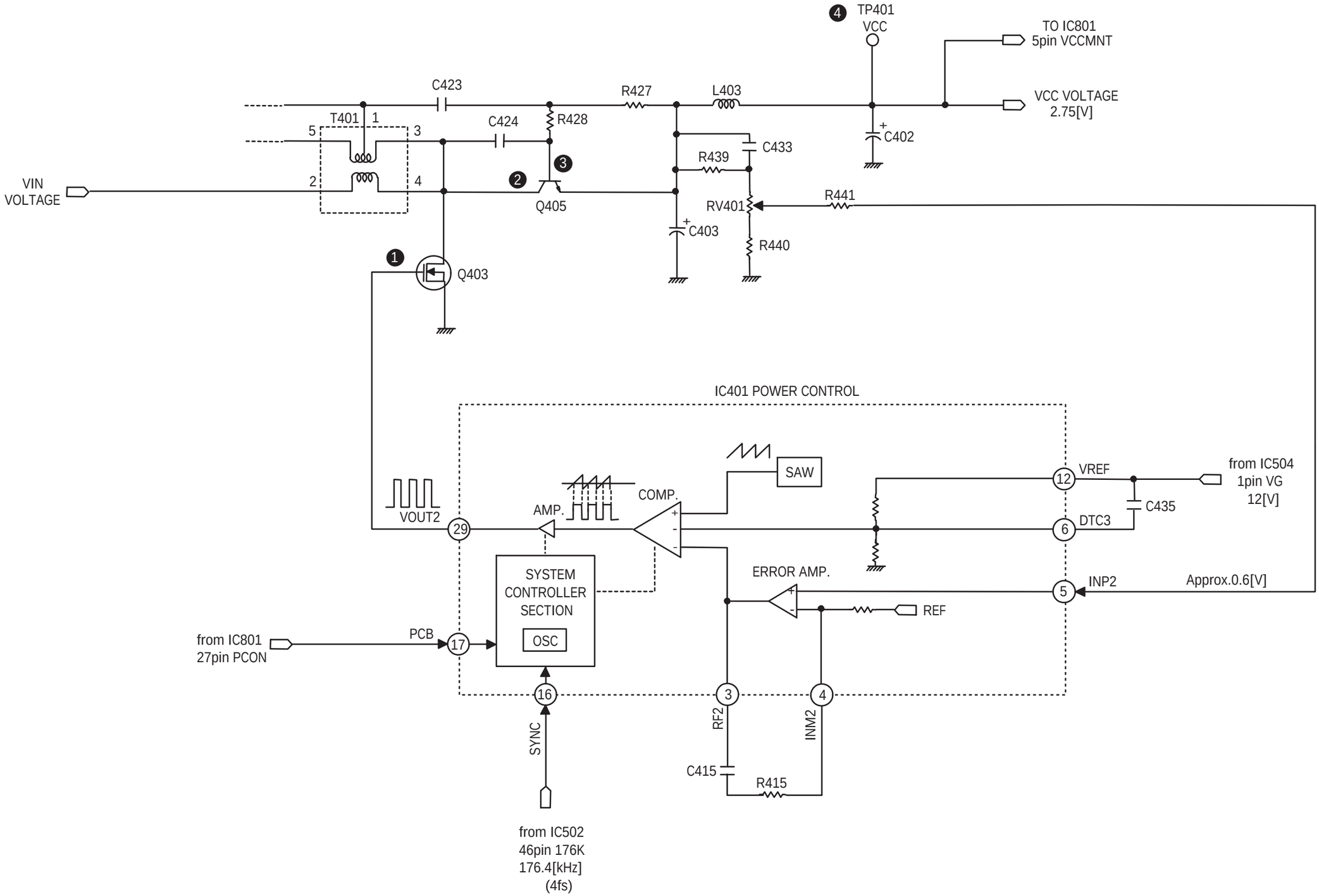



Fig. 2-3 VCC voltage generation circuit block diagram

### 3. Generation of VCC Voltage

Fig. 2-3 shows the VCC voltage generation circuit block diagram.

#### (1) Operation when the operating mode is switched from STOP mode (SLEEP state) to PLAY mode

When either the PLAY key of the Discman or the PLAY key or the FF key or the REW key of the remote control is pressed, the system controller IC801 outputs the "L" signal from pin㉗ [PCON]. When "L" is output, the SYSTEM CONTROLLER section inside IC401 starts its internal operation. As the SYSTEM CONTROLLER section starts internal operation, the PWM waveform that is generated by the PWM comparator inside IC401, is output from pin㉙ [VOUT2] of the POWER CONTROL IC401. As the PWM waveform is output from pin㉙ [VOUT2] of IC401, Q403 and Q405 start the switching operation which starts up the STEP-UP/DOWN DC-DC CONVERTER that generates 2.75 V. The switching output from Q405 is smoothed out by C403 and is divided by the voltage-divider resistors of R439, RV401, and R440. The output voltage from the voltage-divider resistors is fed back to pin⑤ [INP2] of IC401. Based on this feedback voltage, IC401 controls the duty ratio of the PWM waveform that is generated by the PWM comparator, in order to control the output voltage. The switching output from Q405 is at the same time smoothed out by L403 and C402 to generate the VCC voltage (2.75 V ). As the VCC voltage is generated, the DSP IC502 starts up so that the 4fs signal is sent to pin⑯ [SYNC] of the POWER CONTROL IC401. As the 4fs signal is input to IC401, the SYSTEM CONTROLLER section inside IC401 switches the operation clock to the input 4fs signal from internal oscillation to execute its operation.

#### (2) Operation when the operating mode is switched from PLAY mode to STOP mode (SLEEP state)

When either the STOP key of the Discman or that of the remote control is pressed, the system controller IC801 outputs the "H" signal from pin㉗ [PCON]. This "H" signal stops the PWM output from pin㉙ [VOUT2] of the POWER CONTROL IC401 to output the "L" signal. This "L" output turns off Q403 and Q405 and stops outputting the VCC voltage. As the VCC voltage is stopped, the 4fs signal is no longer input to pin⑯ [SYNC] of the POWER CONTROL IC401. When the SYSTEM CONTROLLER section inside IC401 detects that the input to pin⑰ [PCB] goes "H", it stops its internal operation. Note that when the RESUME function is turned off, the system controller IC801 moves the optical pickup to the innermost circumference, and sets the output from pin㉗ [PCON] to "H". When the RESUME function is turned on, the optical pickup is not moved to the innermost circumference.

The waveform timing chart during generation of the VCC voltage is shown in Fig. 2-4.

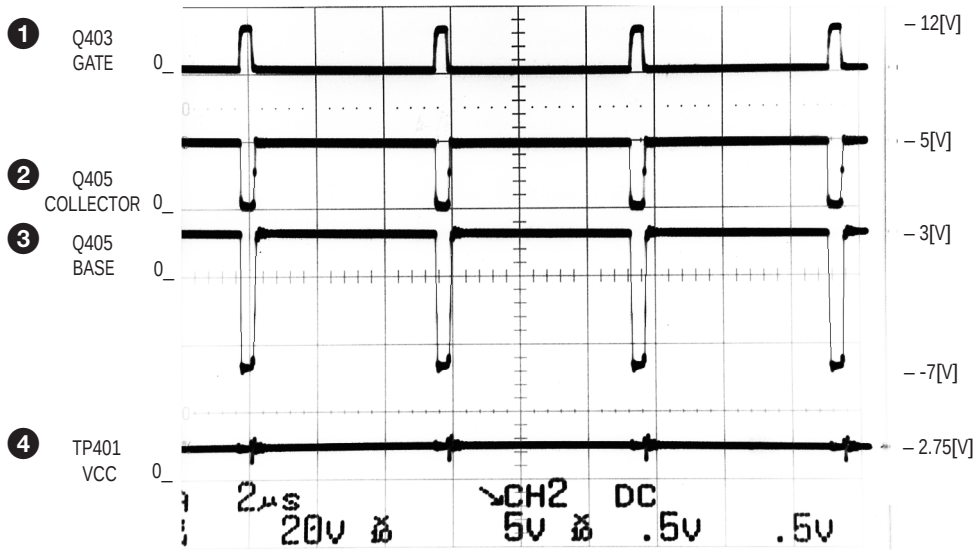



Fig. 2-4 Waveform timing chart during generation of the VCC voltage

### 4. Generation of VG voltage

Figure 2-5 shows the VG voltage generation circuit block diagram.

As the VCC voltage 2.75 V is generated as shown, the D/A CONVERTER IC301 starts up. As IC301 starts up, X301 starts oscillating. Then, the 384fs (16.9 [MHz]) signal is supplied to pin⑭ [XIN] of IC502 as the master clock of the DSP IC502 from pin⑬ [CKO] of IC301. Next, when the DSP IC502 starts up, 4fs (176.4 [kHz]) signal is generated from the 384fs signal that is input to pin⑭ [XIN] using the frequency-divider inside IC502. Then the 4fs (176.4 [kHz]) signal is output from pin㊻ [176K] to pin⑯ [SYNC] of the POWER CONTROL IC401. IC401 then outputs the 4fs (176.4 [kHz]) signal (see Fig. 2-6) to the COIL/MOTOR DRIVE IC504. As the 4fs (176.4) [kHz]) signal is input to the COIL/MOTOR DRIVE IC504, the CHARGE PUMP circuit inside IC504 starts functioning and the VG voltage (approx. 12 V) is generated. Approx. 12 V is output from pin① [VG] of IC504.
Even though the VG voltage is nominally approx. 12 V, it changes in practice depending on the VIN voltage. For information during repair, the CHARGE PUMP circuit inside IC504 is judged to be operating correctly when a voltage approximately three times higher than the input signal to pin㉜ [VCG] of the COIL/MOTOR DRIVE IC504 is output from pin① [VG] of IC504.

The clock timing during generation of the VG voltage is shown in Fig. 2-6.

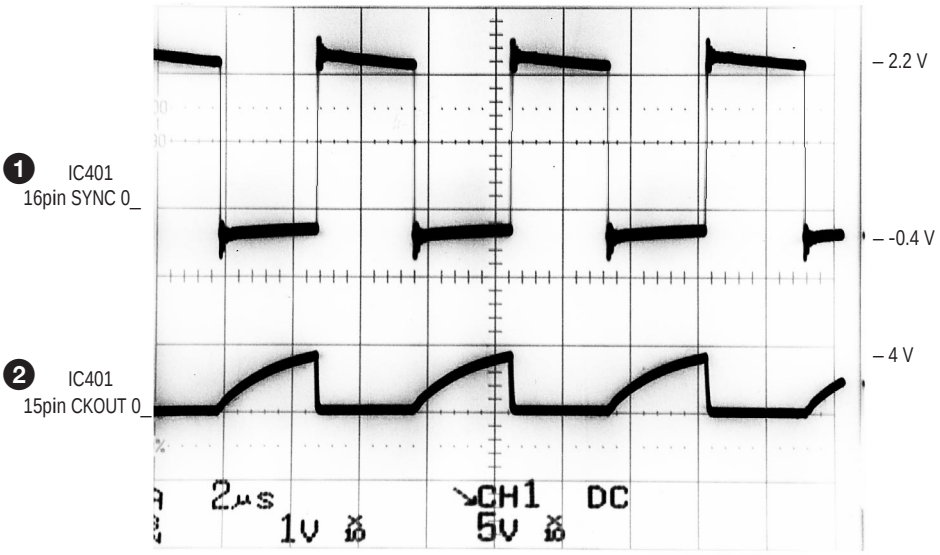



Fig. 2-6 Clock timing during generation of the VG voltage

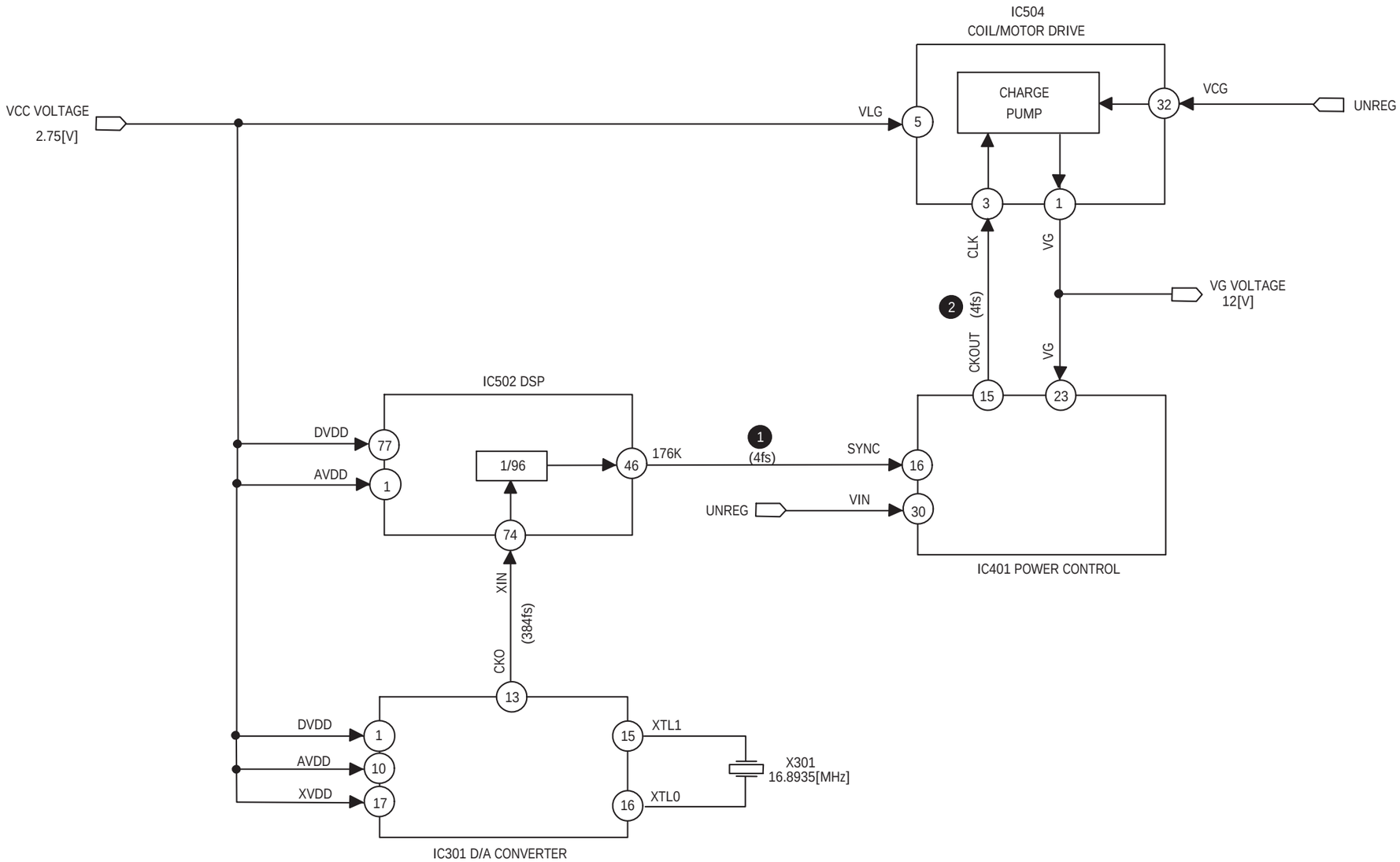



Fig. 2-5 VG voltage generation circuit block diagram

## 2-4. Charging Circuit

Figure 2-7 shows the charging circuit block diagram.

### (1) Operation of the system controller IC801 during charging

When the DC plug is connected to the DC jack, the supplied voltage is supplied to the system controller pin⑤⑦ [DCINMNT] of IC801 and PIN③④ [DCIN] of POWER CONTROL IC401 via D415. Each IC detects that AC adapter is connected. After the system controller IC801 starts up and recognizes that AC adapter is connected, the system controller IC801 detects the rechargeable battery by the input terminal of pin⑥① [CHGMHT2] as described below. When the system controller IC801 recognizes that a voltage is input to pin⑥① [CHGMNT2], an "H" signal is output from pin⑪ [CHGON]. POWER CONTROL IC401 starts the charging operation by this "H" signal.

### = Rechargeable Battery Detection =

The system controller IC801 performs the battery detection by pin⑥① [CHGMNT2]. When the rechargeable battery is inserted (see Fig. 2-8(a)), a voltage is input to pin⑥① [CHGMNT2] because cathode of the supplied rechargeable battery is exposed. When an alkaline dry cell battery (size AA) is inserted (see Fig.2-8(b)), voltage is not input to pin⑥① [CHGMNT2] because cathode of the battery is molded. In the system controller IC801, if no voltage is input to pin⑥① [CHGMNT2] , an "L" signal is output from pin⑪ [CHGON] and the charging operation stops. When batteries are inserted as shown in Fig. 2-8(c), voltage is input to pin⑥① [CHGMNT2] of the system controller IC801. An "L" signal is output from pin⑪ [CHGON] because the system controller IC801 detects that the voltage rise time is fast (Generally, primary cell has a characteristic that the voltage rise time is faster than secondary cell.) and identifies that the inserted battery is not a rechargeable battery, and an "L" signal is output from pin⑪ [CHGON]. Hence, the charging operation stops.

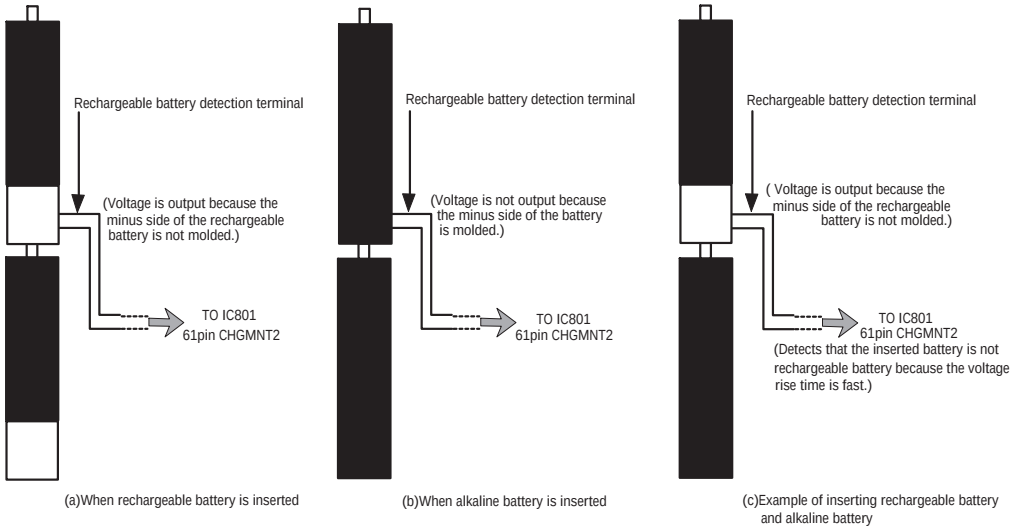



Fig. 2-8 How to detect the rechargeable battery

### (2) Operation of POWER CONTROL IC401 during charging

POWER CONTROL IC401 contains the CHARGE CONTROL section which starts charging when the charge conditions shown in Table. 2-2 are satisfied. When IC401 starts charging, IC401 outputs the "H" signal from pin㉝ [CHGSW]. This "H" signal turns Q401 on. At the same time, IC401 outputs the "H" signal inside IC401 to turn on the N-channel MOS FET Q1. As Q401 is turned on, the voltage that is obtained by I-V converting the current flowing through the recharging battery with external resistors R412 to R414, is input to pin① [RS] of IC401. IC401 keeps the current constant at all times through the rechargeable battery by comparing the input voltage at pin① [RS] with the internal reference voltage (0.35 V) with the ERROR AMP. IC401 has a built-in monitor circuit inside the CHARGE CONTROL section which monitors the charging voltage. The monitoring voltage is output to the system controller IC801 from pin㉛ [CHGOUT].

Table. 2-2 Charge conditions

| | Input | | | Output |
|---|---|---|---|---|
| | Pin ㉞[DCIN] | Pin ⑰[PCB] | Pin ⑱[CHGON] | Pin ㉝[CHGSW] |
| During charging | H | H | H | H |

### (3) Operation when stopping charging

During charging, the system controller IC801 detects a –Δ V (minus delta V potential) by monitoring the voltages that are input to pin㊾ [CHGMNT1] and pin㊶ [CHGMNT2]. When the system controller IC801 detects a –Δ V, it stops charging by setting pin⑪ [CHGON] to "L". In addition to the –Δ V detection system, the system controller IC801 uses the timer system (timer of approx. four hours) at the same time in order to stop charging.

### ■ –Δ V charging system:

This system is most widely used for charging nickel-cadmium and nickel-hydrogen rechargeable batteries. To control charging, this system uses the characteristic that the battery voltage reaches its peak at the charge-end, then decreases as the battery temperature rises due to oxygen gas absorption reaction of the negative electrode. This system is called the –ΔV system. Refer to chapter 5 APPENDIX: TYPES AND APPLICATIONS OF SECONDARY BATTERIES FOR PORTABLE EQUIPMENT (RECHARGEABLE BATTERIES).

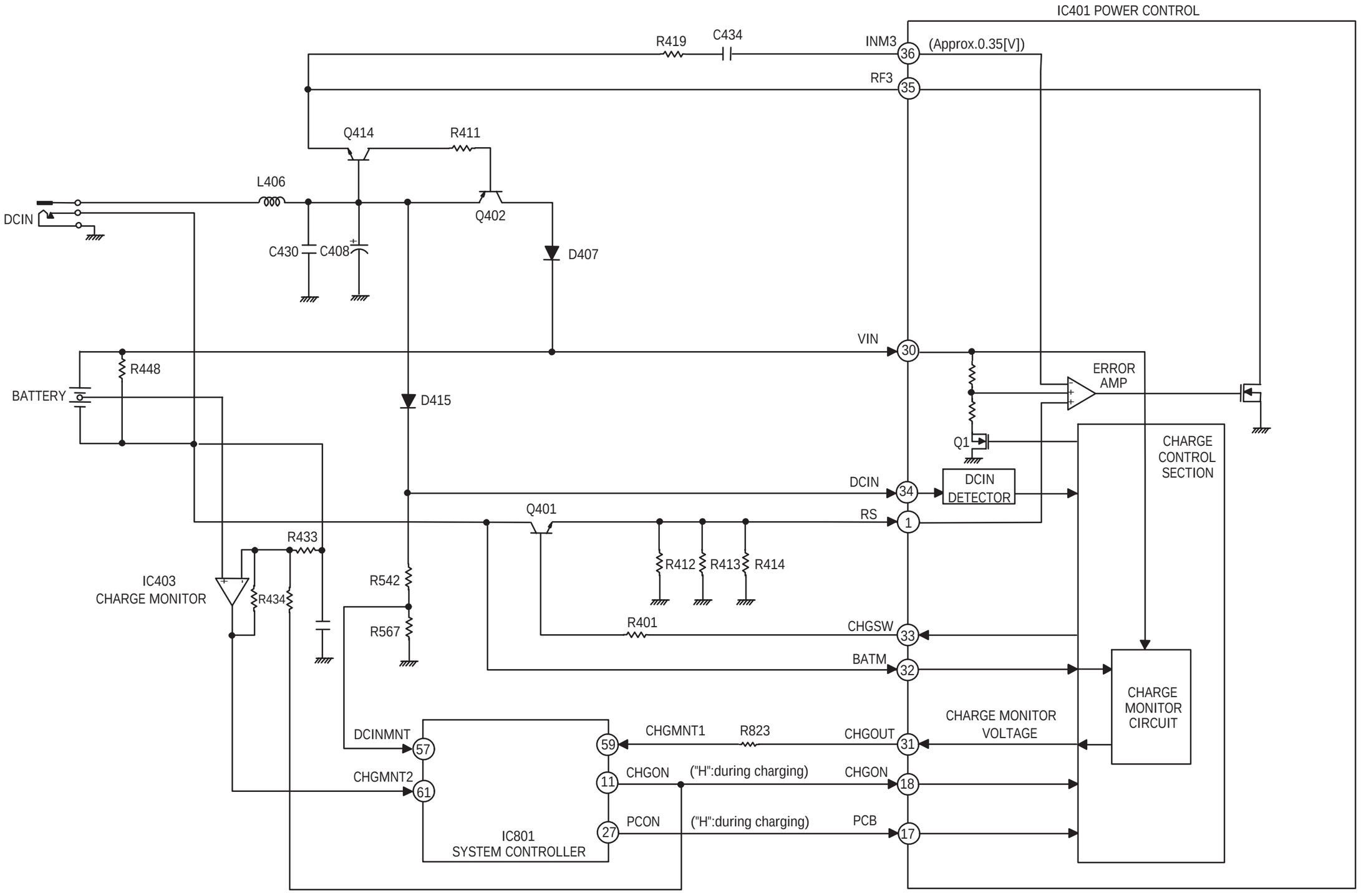



Fig. 2-7 Charging circuit block diagram

## 2-5. APC Circuit

Figure 2-9 shows the APC circuit block diagram.

### (1) AC adapter drive operation

When the system controller IC801 detects that the PLAY key is pressed, IC801 outputs the "L" signal from pin㉗ [PCON]. When "L" is output, the POWER CONTROL IC401 starts its internal operation. As Q411 is turned off, the reference voltage (approx. 2 V) that is obtained by dividing the VCPU voltage by the voltage-divider resistors of R437 and R438, is input to pin⑨ [INP1] of IC401. When the POWER CONTROL IC401 starts its internal operation, the switching circuit inside IC401 starts and the APC (Automatic Power Control) circuit also starts so that the feedback voltage to pin⑧ [INM1] is maintained at 2 V at all times. During AC adapter drive operation, the power voltage of 4.5 V is input to it, so only the step-down circuit consisting of the switching output from pin㉖ [VOUT1] of IC401, Q406, D410, L402, and C437, works. During AC adapter drive operation, the "L" signal is output from pin㉔ [UPCK1] of IC401 while the "H" signal is output from pin㉕ [UPCK1B]. Thus the step-up circuit of the APC circuit does not operate (see Fig. 2-10 (1)).

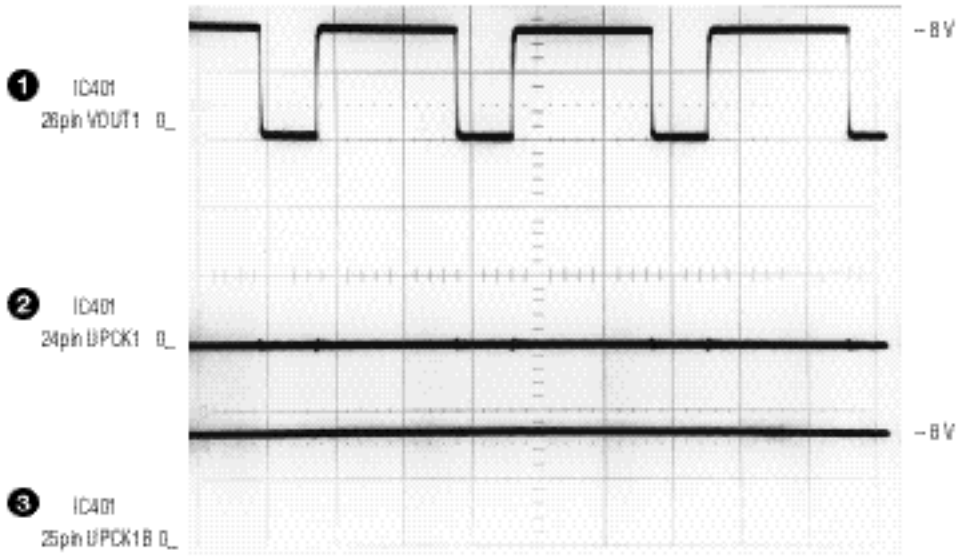
### (2) Battery drive operation

During battery drive operation, the APC circuit is controlled so that the feedback voltage to pin⑧ [INM1] of IC401 stays at 2 V at all times in the same manner as in the AC adapter drive operation. However, the step-up circuit of the APC circuit works when the battery voltage decreases. When the battery voltage decreases while the APC circuit is operating, the input voltage to pin⑧ [INM1] of IC401 decreases. As the input voltage to pin⑧ [INM1] of IC401 decreases, the output voltage from the ERROR AMP inside IC401 (i.e., output of pin⑦ [RF1] of IC401) increases which decreases the input voltage to pin⑪ [DTC1]. Hence, the reference input voltage to COMPARATOR 2 inside IC401 decreases so that a PWM waveform having a high duty ratio is output from COMPARATOR 2. The PWM waveform thus generated is output from pin㉔ [UPCK1] and pin㉕ [UPCK1B] (see Fig. 2-10 (2)). Then Q407 and Q408 start switching operation and the step-up circuit is activated. The APC circuit functions so that the feedback voltage to pin⑧ [INM1] stays at 2 V at all times.

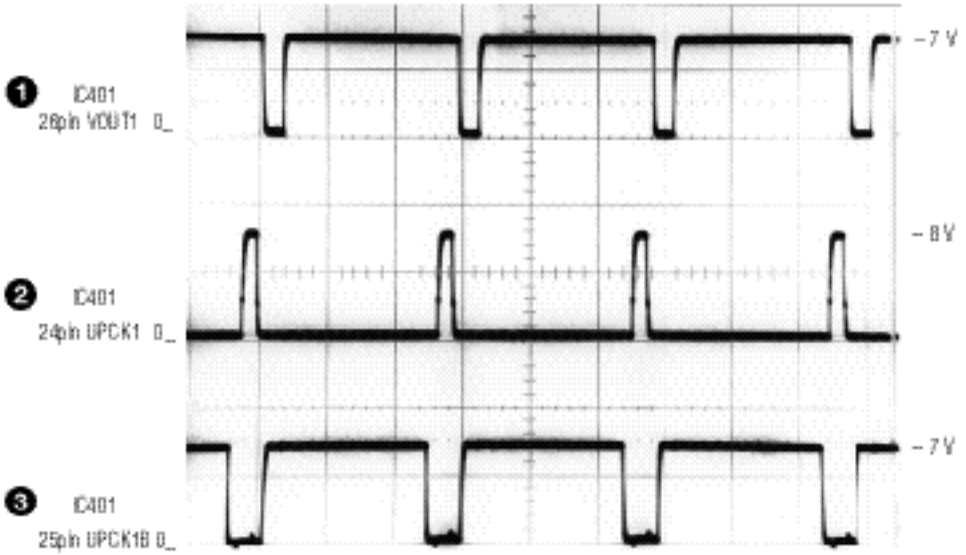
The Discman power supply has a built-in protection circuit that protects the laser diode from damage in case the power supply suffers a momentary failure. When the power supply is momentarily shut down, Q417 is turned on and so the voltage that is obtained by dividing the VCPU voltage by the voltage-divider resistors of R422 and R432, is sent to Q411 which turns on Q411. This decreases the reference voltage input to the APC circuit, i.e., pin⑨ [INP1] that protects the laser diode from damage.

Figure 2-10 shows the operation waveforms of the APC circuit during battery drive operation.

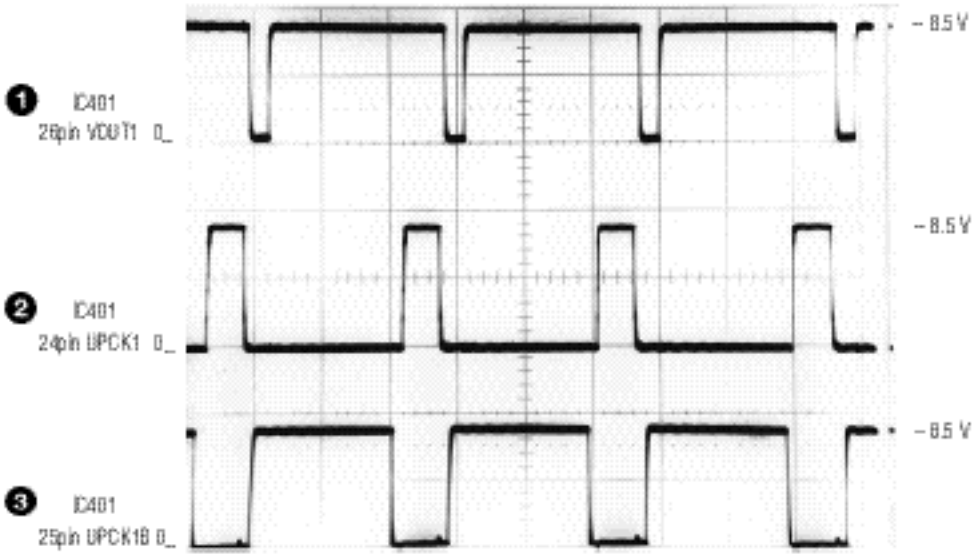
Describing the APC operation in more detail, the APC circuit operation maintains the PD value to 150 mV using a feedback loop inside the RF AMP IC501. When the PD value is 150 mV, the input voltage to pin⑧ [INM1] of POWER CONTROL IC401 becomes approx. 2 V.




(1) APC circuit operation waveforms
(When AC adapter drive operation, battery voltage of 3V is supplied. )




(2) APC circuit operation waveforms (When battery voltage of 2.5 V is supplied)




(3) APC circuit operation waveforms (When battery voltage of 2 V is supplied)

Fig. 2-10 APC circuit operation waveforms (During battery drive operation)

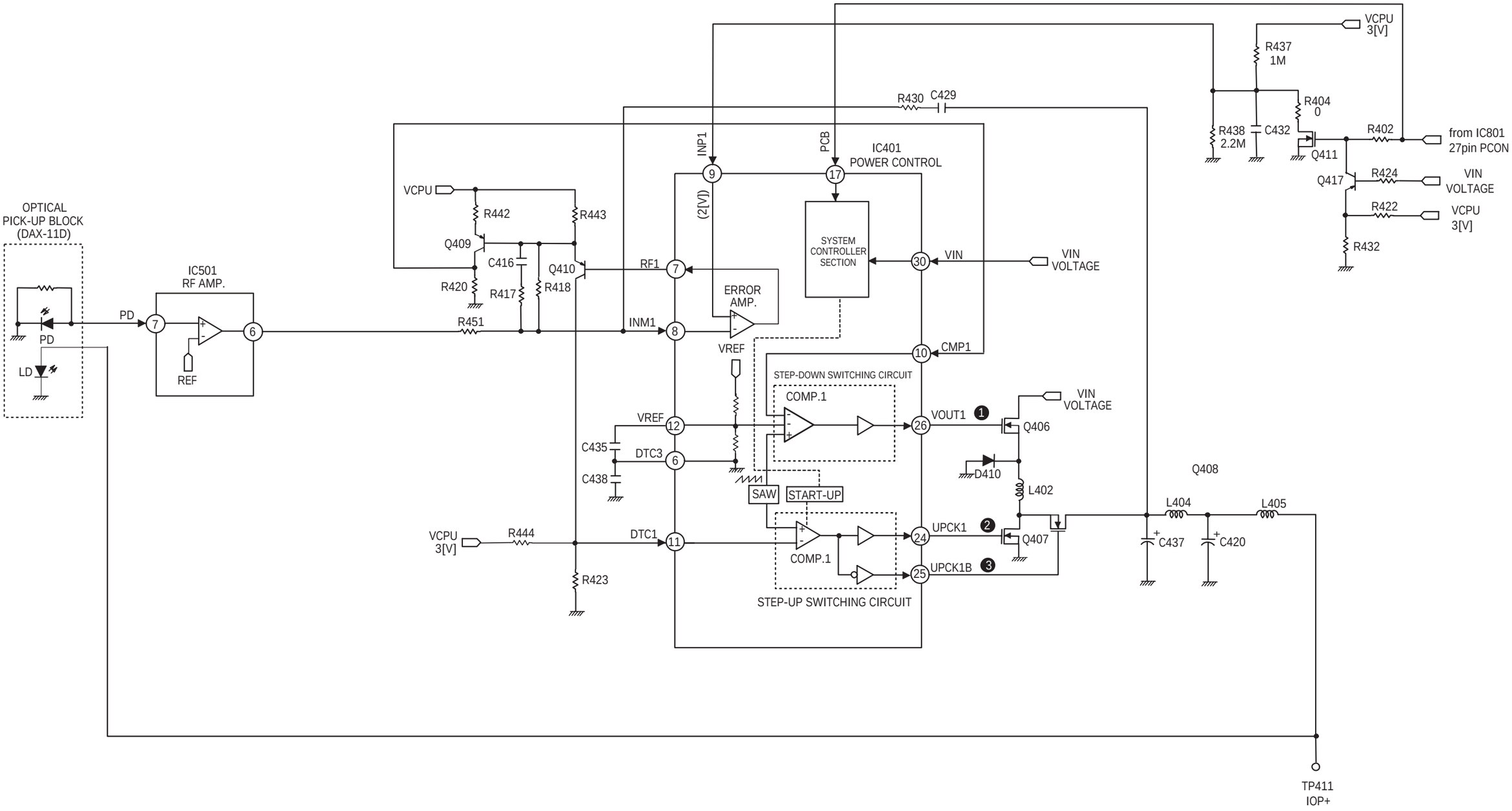



Fig. 2-9 APC circuit block diagram

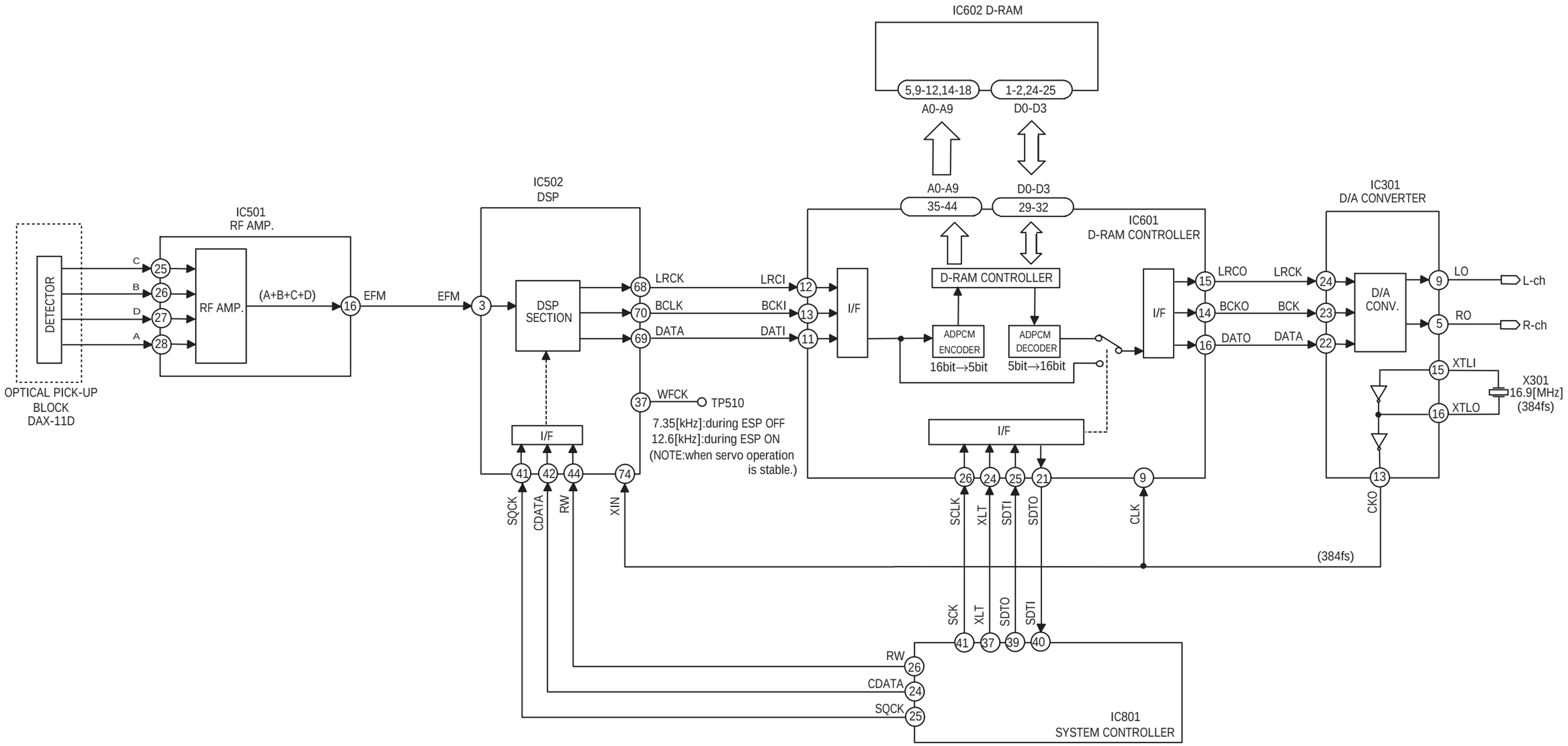



Fig. 2-11 ESP (Electronic Shock Protection) circuit block diagram

### 2-6. ESP (Electronic Shock Protection) Circuit

Figure 2-11 shows the ESP (Electronic Shock Protection) circuit block diagram.

#### (1) Generation of DA DATA

The signals of A to D that are picked up by the detectors of the optical pickup, are input to the RF AMP IC501 where the EFM signal is generated by the RF AMP inside IC501. The EFM signal thus generated is output to pin③ [EFM] of the DSP IC502 from pin⑯ [EFM] of IC501. In the DSP IC502, various signal processing (14-8 demodulation, de-interleaving, error correction, etc.) is performed on the input EFM signal to generate the DA DATA. The DA DATA thus generated is output to the D-RAM CONTROLLER IC601 with the L-ch data and the R-ch data alternately, in synchronization with LRCK (L-channel/R-channel discrimination signal) that is output from pin⑱ [LRCK] of DSP IC502, and also in synchronization with BLCK (bit clock) that is output from pin⑳ [BCLK]. The BCLK (48fs) and LRCK (fs) signals that are generated by the DSP IC502, are generated by a frequency-divider inside IC502 based on the 384fs signal that is input to pin㉔ [XIN].

#### (2) Operation of the D-RAM CONTROLLER IC601

Operation of the D-RAM CONTROLLER IC601 when the ESP function is on is as follows. The DA DATA that is input to the D-RAM CONTROLLER IC601 when the ESP function is on, is input to ADPCM ENCODER inside IC601, and is compressed to 5-bit data. The DA DATA compressed to 5-bit data is sequentially stored in the D-RAM IC602 through the D-RAM CONTROLLER block inside IC601. Then the 5-bit data that is read from the D-RAM IC602 enters the ADPCM DECODER block where it is decoded to 16-bit data. The DA DATA thus decoded is output to the D/A CONVERTER IC301 with the L-ch data and the R-ch data alternately, in synchronization with LRCK (L-channel/R-channel discrimination signal) that is output from pin⑮ [LRCO] of IC601, and also in synchronization with BLCK (bit clock) that is output from pin⑭ [BCKO].
Next, operation of the D-RAM CONTROLLER IC601 when the ESP function is off, is described. When the D-RAM CONTROLLER IC601 recognizes that the ESP function is turned off by the commands (refer to the commands described below) that are sent from the system controller IC801, the switches in IC601 are activated to set the internal operation of the Discman to the pass-through state. Then, the DA DATA is output to the D/A CONVERTER IC301 with the L-ch data and the R-ch data alternately, in synchronization with LRCK (L-channel/R-channel discrimination signal) that is output from pin⑮ [LRCO] of IC601, and also in synchronization with BLCK (bit clock) that is output from pin⑭ [BCKO].
Here, the BCLK (48fs) and LRCK (fs) signals that are generated by DSP IC601, are generated by a frequency-divider inside IC601 based on the 384fs signal that is input to pin⑨ [CLK]. The BCLK and LRCK signals that are generated inside DSP IC502 are in synchronization with the BCLK and LRCK signals that are generated by the D-RAM CONTROLLER IC601.

♦ Interface between the system controller IC801 and the D-RAM CONTROLLER IC601

**= From the system controller IC801 ⟶ D-RAM CONTROLLER IC601 =**
• Turning ON and OFF the ESP
• Turning ON and OFF the ADPCM ENCODER block and the ADPCM DECODER block.

**= From the D-RAM CONTROLLER IC601 ⟶ system controller IC801**
• Data writing status of the D-RAM IC602 (availability of the data writing area inside the D-RAM IC602, etc.)

#### (3) Generation of Analog Signal

The DA data that is sent to the D/A CONVERTER IC301 is D/A converted by the D/A CONVERTER inside IC301, and is output from pin⑨ [LO] and pin⑤ [RO] as the L-ch and the R-ch analog signal.

# 3. OPERATION OF THE D-365 SERIES POWER SUPPLY CIRCUIT

### 3-1. Types of Power Supply

The D-365 series compact CD player can be operated on the following three types of power supply.

- ♦ DC power supply
  - • AC adapter ..... 4.5 V (supplied)
- ♦ Battery
  - • Dry cell battery (size AA, 2pcs) ..... 3.0 V (optional), or
  - • Rechargeable nickel-hydrogen battery (BP-DM20) ..... 2.4 V (supplied)

### 3-2. Identifying the Power Supplies

When the system controller IC801 is started up, it identifies from where the main power voltage is supplied. It also stops operation if batteries that do not satisfy the specifications are used. The system controller IC identifies the power supplies from the following three detections.

(1) Pin ⑤⑦[DCINMNT] : The voltage that is obtained by dividing the DCIN input voltage by the resistors.

(2) Pin ⑤⑧[BATMNT] : The voltage that is obtained by dividing the battery terminal voltage by the resistors.

(3) Pin ③②[XRCHG] : The result of the rechargeable battery detection switch ("L": When the rechargeable battery is inserted)

Table 3-1 Power supply identification table

| | | Pin ⑤⑦[DCINMNT] | Pin ⑤⑧[BATMNT] | Pin ③②[XRCHG] |
|---|---|---|---|---|
| DC supply (from AC adapter) | | H | H | H (L*3-1) |
| Battery | Rechargeable battery | L | H | L |
| | Dry cell battery | L | H | H |

* 3-1: When a rechargeable battery is inserted, the input of pin ③②[XRCHG] goes low.

### 3-3. Circuit Voltage

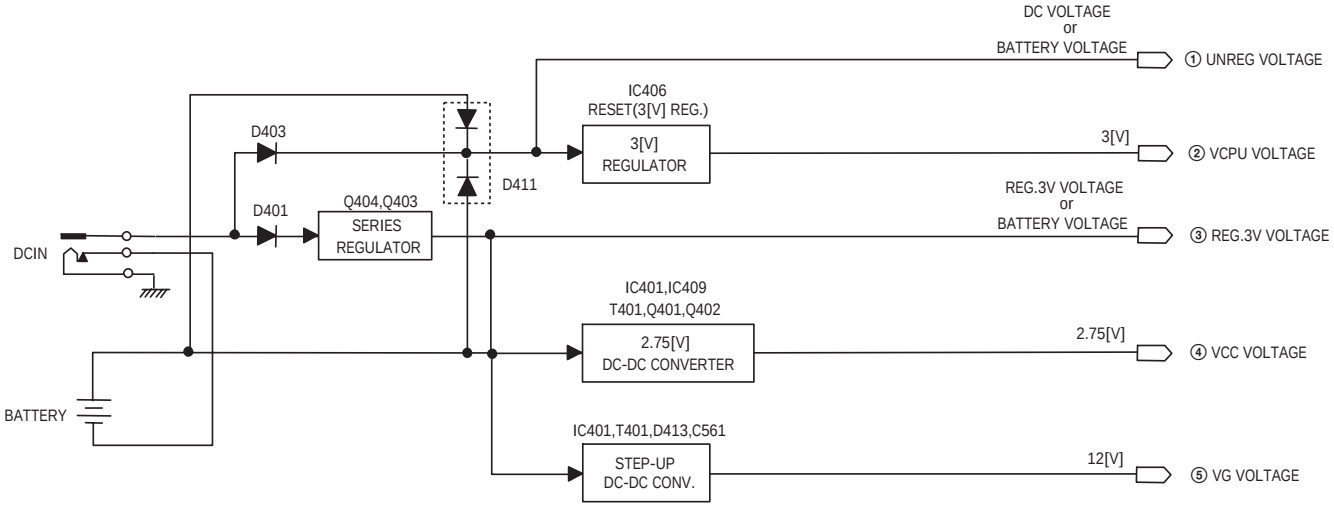



Fig. 3-1 Power supply voltage generation block diagram

During AC adapter drive operation, the following five outputs of the power supply voltage are generated. (Refer to Fig. 3-1.)

① UNREG voltage
- The UNREG voltage that is supplied to the DC jack from the AC adapter, which is 4.5 V.
- When the Discman is operated on battery, the battery terminal voltage is supplied as the UNREG voltage through D411.

② VCPU voltage ⟶ "RESET IC406"
- This voltage drives the system controller IC801, and is 3.0 V.

③ REG. 3 V voltage ⟶ "SERIES REGULATOR (Q404, Q403)"
- The voltage that is supplied to the DC jack from external AC adapter, is regulated by the SERIES REGULATOR (Q404, Q403), and is supplied as the REG. 3 V voltage.
- When the Discman is operated on battery, the battery terminal voltage is supplied as the REG. 3 V voltage through D411.

④ VCC voltage ⟶ "2.75 V DC-DC CONVERTER (SWITCHING REGULATOR IC401, T401, Q401, Q402 etc.)"
- This voltage is used by the RF AMP IC501, DIGITAL SIGNAL PROCESSOR IC502, COIL/MOTOR DRIVE IC504, etc., and is 2.75 V.

⑤ VG voltage ⟶ "STEP-UP DC-DC CONVERTER (SWITCHING REGULATOR IC401, T401, D413, C561)"
- This voltage is used the power supply of the pre-driver inside IC504, and is approx. 12 V.

Generation of the respective voltages is described below.

### 1. Generation of VCPU Voltage

The VCPU voltage generation circuit block diagram is shown in Fig. 3-2.

#### (1) AC adapter drive operation

When the DC plug of the AC adapter is connected to the DC jack, approx. 4.5 V is sent to pin⑥ [VDD] of the RESET IC401 via D403 and D411, which starts up the RESET IC406. As IC406 is started up, the VCPU voltage 3.0 V is generated by the SERIES REGULATOR inside the RESET IC406. The VCPU voltage thus generated is sent from pin⑤ [VOUT] to pin① [VDD] and pin㊼ [VDD] of the system controller IC801 to start up the system controller IC801.

#### (2) Battery drive operation

When the battery is inserted, the battery voltage is sent to pin⑥ [VDD] of the RESET IC406 via D411 to start up the RESET IC406. The RESET IC406 has a built-in VDD voltage detection circuit so that the input voltage to pin⑥ [VDO] is at all times maintained at 3.3 V or higher by the self step-up operation using the switching output from pin⑧ [LX], L402, D406 and C416. On the other hand, the input voltage to pin⑥ [VDD] of the RESET IC406 is input to the SERIES REGULATOR inside IC406 to generate the VCPU voltage 3.0 V. The VCPU voltage thus generated is sent from pin⑤ [VOUT] to pin① [VDD] and pin㊼ [VDD] of the system controller IC801 to start up IC801. The step-up circuit inside IC401 operates only when a Discman is in the STOP mode because the step-up circuit of the RESET IC406 has a large power consumption. When a Discman is in the PLAY mode, the 2.75 V generator circuit, which is discussed later, starts operation. Q411 (1/2) and Q411 (2/2) are turned on by this VCC voltage so that the REG. 3 V signal is input to pin② [CE/] of the RESET IC406. The step-up circuit inside IC406 is set into the STOP state by this input signal. The output voltage (3.6 V or higher) that is obtained by the step-up circuit consisting of the switching output from pin⑤ [OUT] of IC401, Q402, T401, D407 and C416, is supplied to pin⑥ [VDD] of the RESET IC406 to generate the stable VCPU voltage even though the step-up circuit of IC406 does not operate.

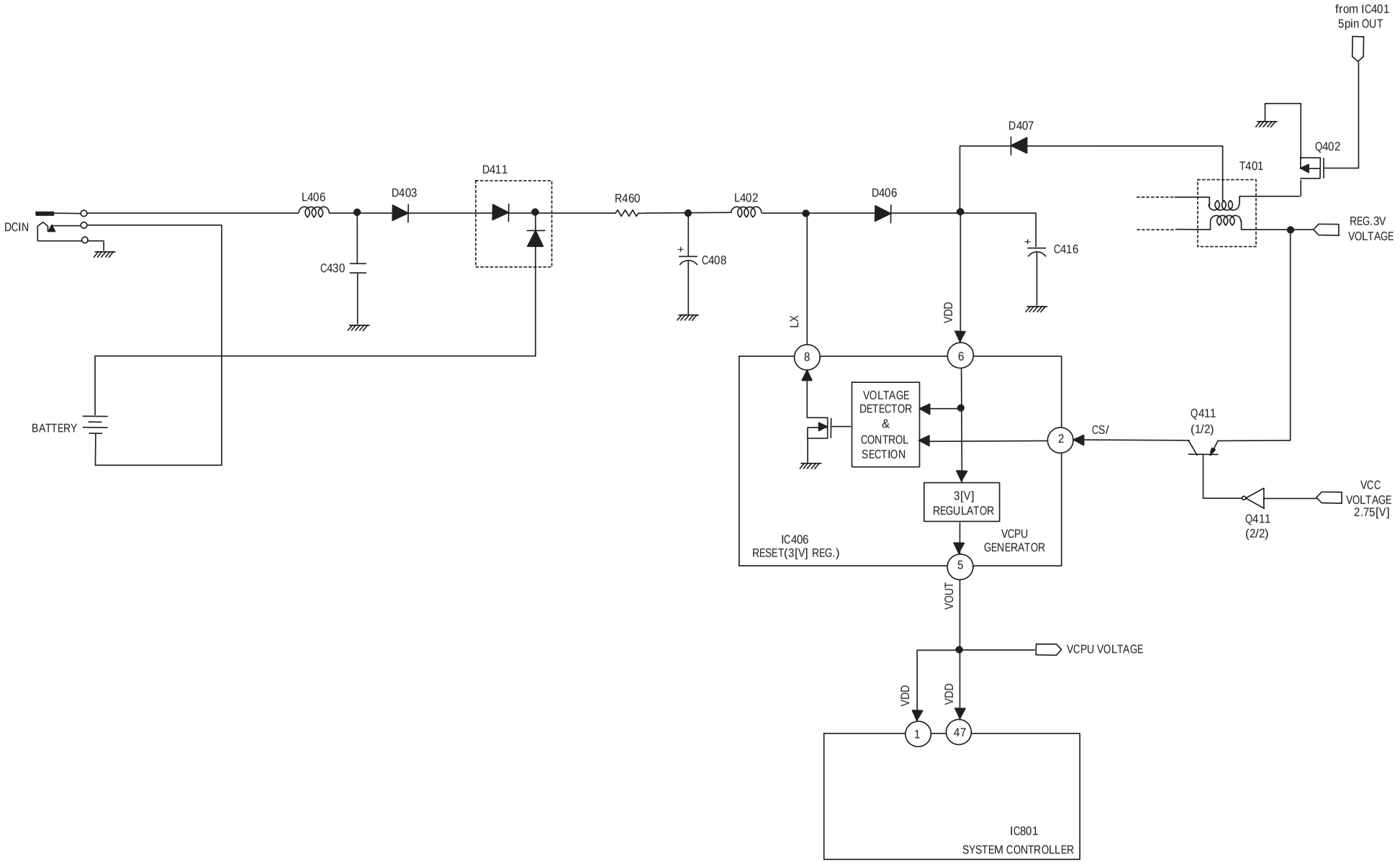



Fig. 3-2 VCPU voltage generation circuit block diagram

## 2. Generation of VCC Voltage

Fig. 3-3 shows the VCC voltage generation circuit block diagram.

### (1) Operation when the operating mode is switched from STOP mode (SLEEP state) to PLAY mode

When either the PLAY key of the Discman or the PLAY key or the FF key or the REW key of the remote control is pressed, the system controller IC801 outputs the "L" signal from pin㉗ [PCON]. When "L" is output, Q415 and Q412 are turned on by this "L" signal so that the input to pin② [CTL] of the SWITCHING REGULATOR IC401 is set to "L" to start the SWITCHING REGULATOR IC401. As the SWITCHING REGULATOR IC401 starts, the internal oscillator of IC401 starts oscillating so that the PWM waveform that is generated by the PWM comparator inside IC401, is output from pin⑤ [OUT] of the SWITCHING REGULATOR IC401. As the PWM waveform is output from pin⑤ [OUT] of IC401, Q402 and Q401 start the switching operation which starts up the STEP-UP/DOWN DC-DC CONVERTER that generates 2.75 V. The switching output from Q401 is smoothed out by L401 and C403, and is divided by the voltage-divider resistors of R401, RV401, and R402. The output voltage from the voltage-divider resistors is fed back to pin① [IN] of IC401. Based on this feedback voltage, IC401 controls the duty ratio of the PWM waveform that is generated by the PWM comparator, in order to control the output voltage, then to generate the VCC voltage (2.75 V).

### (2) Operation when the operating mode is switched from PLAY mode to STOP mode (SLEEP state)

When either the STOP key of the Discman or that of the remote control is pressed, the system controller IC801 outputs the "H" signal from pin㉗ [PCON]. Q412 is turned off by this "H" signal which stops the SWITCHING REGULATOR IC401, and stops outputting the VCC voltage 2.75 V. Note that when the RESUME function is turned off, the system controller IC801 moves the optical pickup to the innermost circumference, and sets the output from pin㉗ [PCON] to "H". When the RESUME function is turned on, the optical pickup is not moved to the innermost circumference.

The waveform timing chart during generation of the VCC voltage is shown in Fig. 3-4.

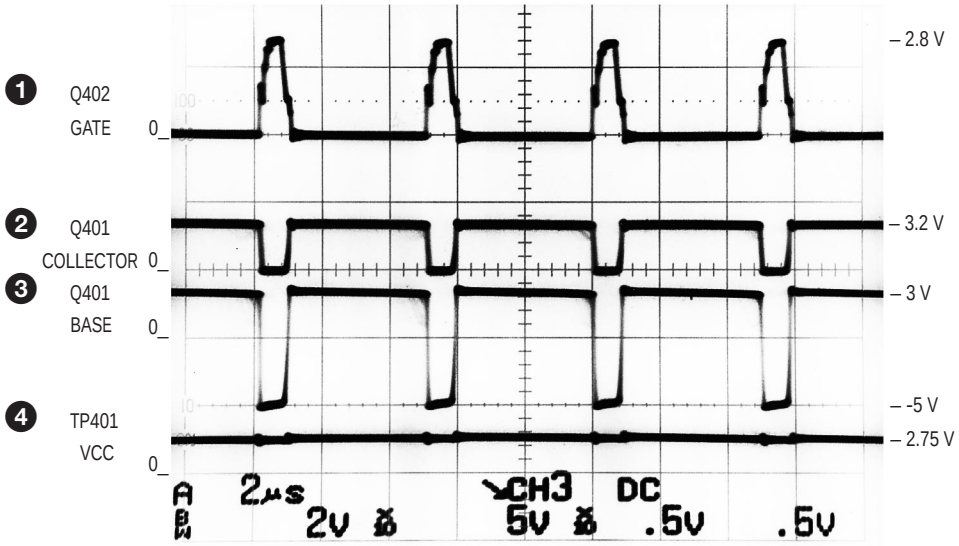



Fig. 3-4 Waveform timing chart during generation of the VCC voltage

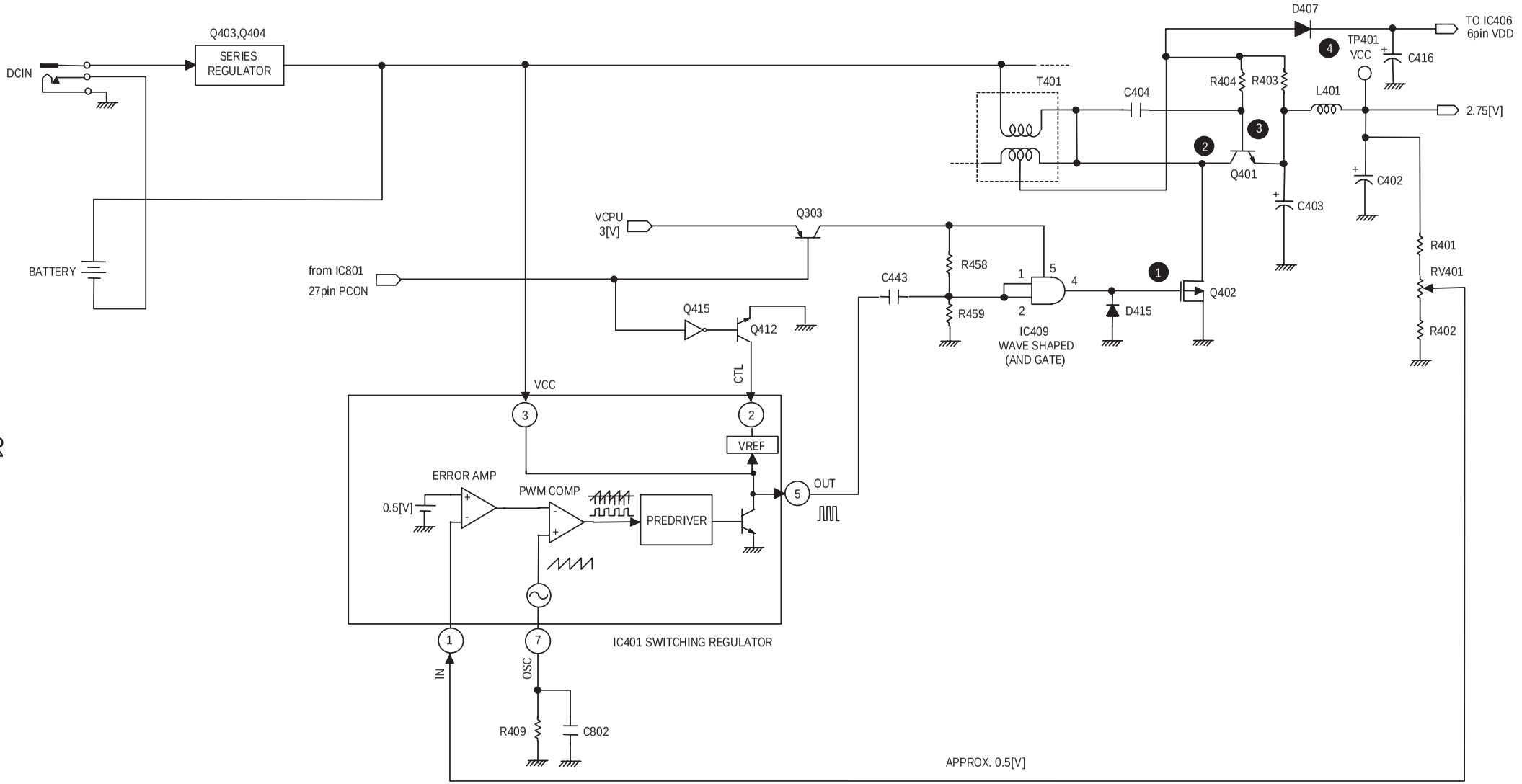



Fig. 3-3 VCC voltage generation circuit block diagram

## 3. Generation of VG voltage

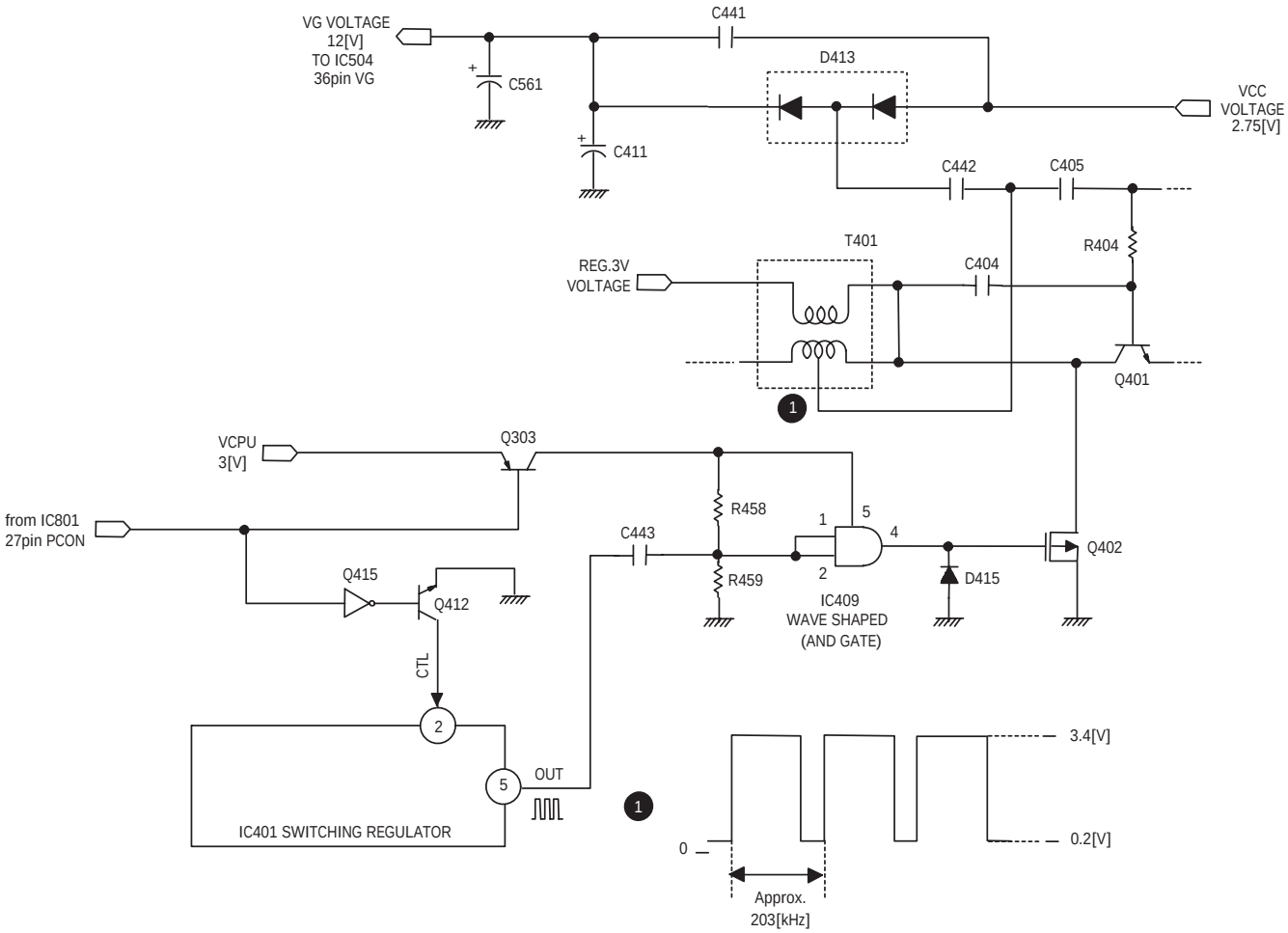



Fig. 3-5 VG voltage generation circuit block diagram

Figure 3-5 shows the VG voltage generation circuit block diagram. When the PLAY key is pressed, the system controller IC801 outputs the "L" signal from pin㉗ [PCON]. When "L" is output, Q415 and Q412 are turned on by this "L" signal so that the input to pin② [CTL] of the SWITCHING REGULATOR IC401 is set to "L" to start the SWITCHING REGULATOR IC401. As the SWITCHING REGULATOR IC401 starts, the internal oscillator of IC401 starts oscillating so that the PWM waveform that is generated by the PWM comparator inside IC401, is output from pin⑤ [OUT] of the SWITCHING REGULATOR IC401. As the PWM waveform is output from pin⑤ [OUT] of IC401, the STEP-UP DC-DC CONVERTER consisting of T401, D413, C411, C561 and the output switching waveform, starts to generates the VG voltage (approx. 12 V) from the REG. 3 V. The VG voltage thus generated, is output to pin㊱ [VG] of the COIL/MOTOR DRIVE IC504.

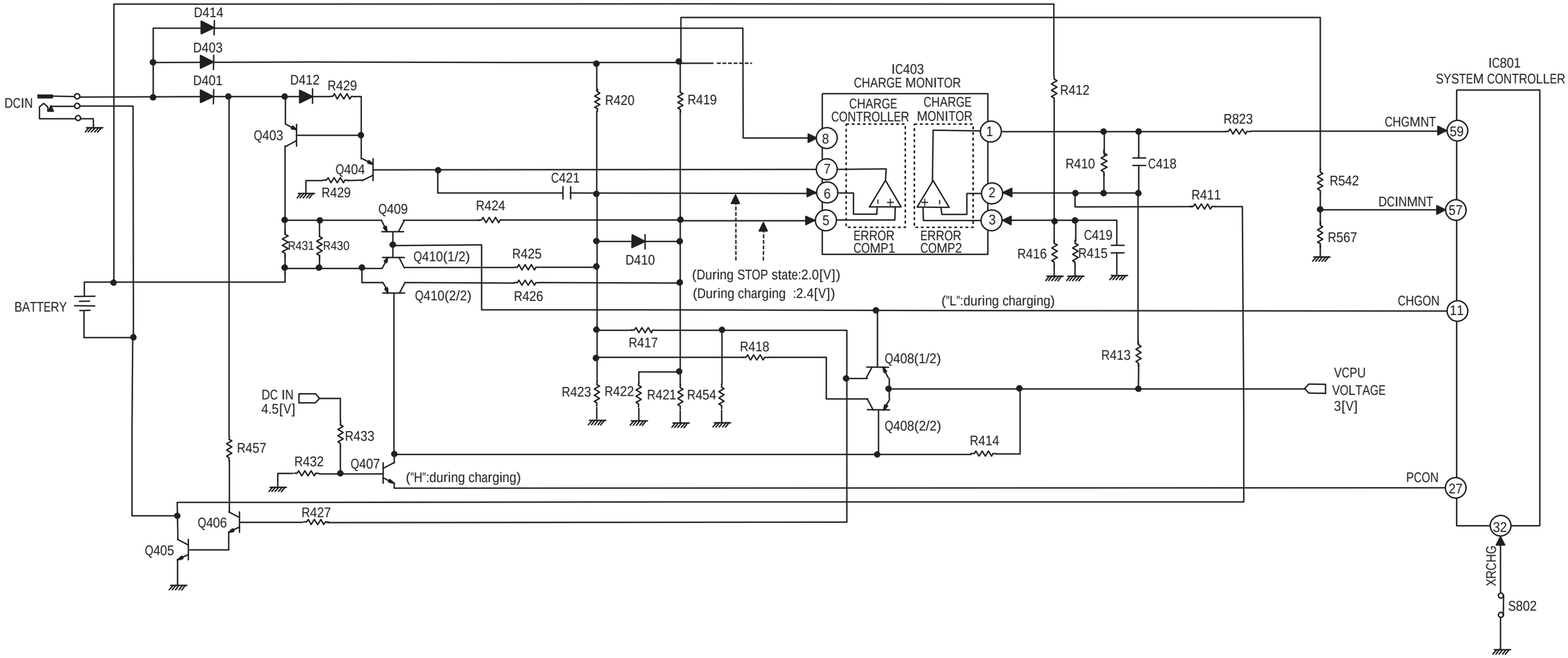



Fig. 3-6 Charging circuit block diagram

## 3-4. Charging Circuit (Operation of the CHARGE MONITOR IC403)

Figure 3-6 shows the charging circuit block diagram.

### (1) Operation of the system controller IC801 during charging

When the DC plug is connected to the DC jack, the system controller IC801 starts up. When the system controller IC801 starts up, the system controller IC801 detects if the Discman satisfies the following charging conditions or not. After the system controller IC801 recognizes that the following conditions are satisfied, it outputs the "L" signal from pin⑪ [CHGON]. Q408 (1/2), Q406 and Q405 are turned on by this "L" signal so that the negative (-) terminal of a battery is connected to ground. At the same time, Q409 and Q410 (1/2) are turned on which starts charging.

♦ Charging conditions

1. The Discman operates on DC (output from AC adapter) ⟶ pin㊼ [DCINMNT] of system controller IC801: "H"
2. The rechargeable battery (BP-DM20) is inserted in the Discman ⟶ pin㉜ [XRCHG] of system controller IC801: "L"
3. The Discman is in the STOP state ⟶ pin㉗ [PCON] of system controller IC801 outputs the "H" signal.

### (2) Operation when charging

When charging starts, the reference voltage that is input to pin⑥ of the CHARGE MONITOR IC403 becomes approx. 2.4 V. At the same time, the voltage that is obtained by I-V converting the current flowing through the rechargeable battery with external resistors R431 and R430, is input to pin⑤ of IC403. The ERROR COMPARATOR1 inside IC403 keeps the charging current that flows through the rechargeable battery constant at all times by comparing the input voltage at pin⑤ with the reference voltage (approx. 2.4 V) and by controlling the pin⑦ output. The CHARGE MONITOR IC403 has an internal ERROR COMPARATOR 2 which monitors the charge voltage that is charged to the rechargeable battery with the MONITOR circuit. The monitoring voltage is output to the system controller from pin㊾ [CHGOUT] of IC801.

### (3) Operation when stopping charging

During charging, the system controller IC801 detects a –Δ V (minus delta V potential) by monitoring the voltages that are input to pin㊾ [CHGMNT]. When the system controller IC801 detects a –Δ V, it stops charging by setting pin⑪ [CHGON] to "H". In addition to the –Δ V detection system, the system controller IC801 uses the timer system (timer of approx. three hours) at the same time in order to stop charging.

### (4) Operation of the CHARGE MONITOR IC403 during playback

During playback, the COMPARATOR1 inside the CHARGE MONITOR IC403 functions as the SERIES REGULATOR. First, when the PLAY key is pressed, the system controller IC801 outputs the "L" signal from pin㉗ [PCON]. When "L" is output, Q408 (2/2) and Q410 (2/2) are turned on by this "L" signal so that the reference voltage (approx. 2.4 V) is input to pin⑥ of the CHARGE MONITOR IC403. At the same time, a voltage passed through the SERIES REGULATOR which consists of Q403 and Q404 is input to pin⑤ of IC403 after divided by R426, R422 and R421. The ERROR COMPARATOR1 inside IC403 controls the output from pin⑦ to keep the output voltage from the SERIES REGULATOR to be constantly 3.0V (REG.3V voltage) by comparing the input voltage to pin⑤ with the input voltage to pin⑥.

# 4. OPERATION OF THE D-245 SERIES POWER SUPPLY CIRCUIT

## 4-1. Types of Power Supply

The D-245 series compact CD player can be operated on the following three types of power supply.

♦ DC power supply
  • AC adapter ..... 4.5 V (supplied)

♦ Battery
  • Dry cell battery (size AA, 2 pcs) ..... 3.0 V (optional), or
  • Rechargeable nickel-hydrogen cadmium battery (BP-DM10) ..... 2.4 V (supplied)

## 4-2. Identifying the Power Supplies

When the system controller IC801 is started up, it identifies from where the main power voltage is supplied. It also stops operation if batteries that do not satisfy the specifications are used. The system controller IC identifies the power supplies from the following three detections.

(1) Pin ㉙[DCINMNT] : The voltage that is obtained by dividing the DCIN input voltage by the resistors.

(2) Pin ㉓[BATMNT] : The voltage that is obtained by dividing the battery terminal voltage by the resistors.

(3) Pin ⑮[XRCHG] : The result of the rechargeable battery detection switch ("L": When the rechargeable battery is inserted)

Table 4-1 Power supply identification table

| | | Pin ㉙[DCINMNT] | Pin ㉓[BATMNT] | Pin ⑮[XRCHG] |
|---|---|---|---|---|
| DC supply (from AC adapter) | | H | H | H (L[*4-1]) |
| Battery | Rechargeable battery | L | H | L |
| | Dry cell battery | L | H | H |

* 4-1: When a rechargeable battery is inserted, the input of pin ⑮[XRCHG] goes low.

## 4-3. Circuit Voltage

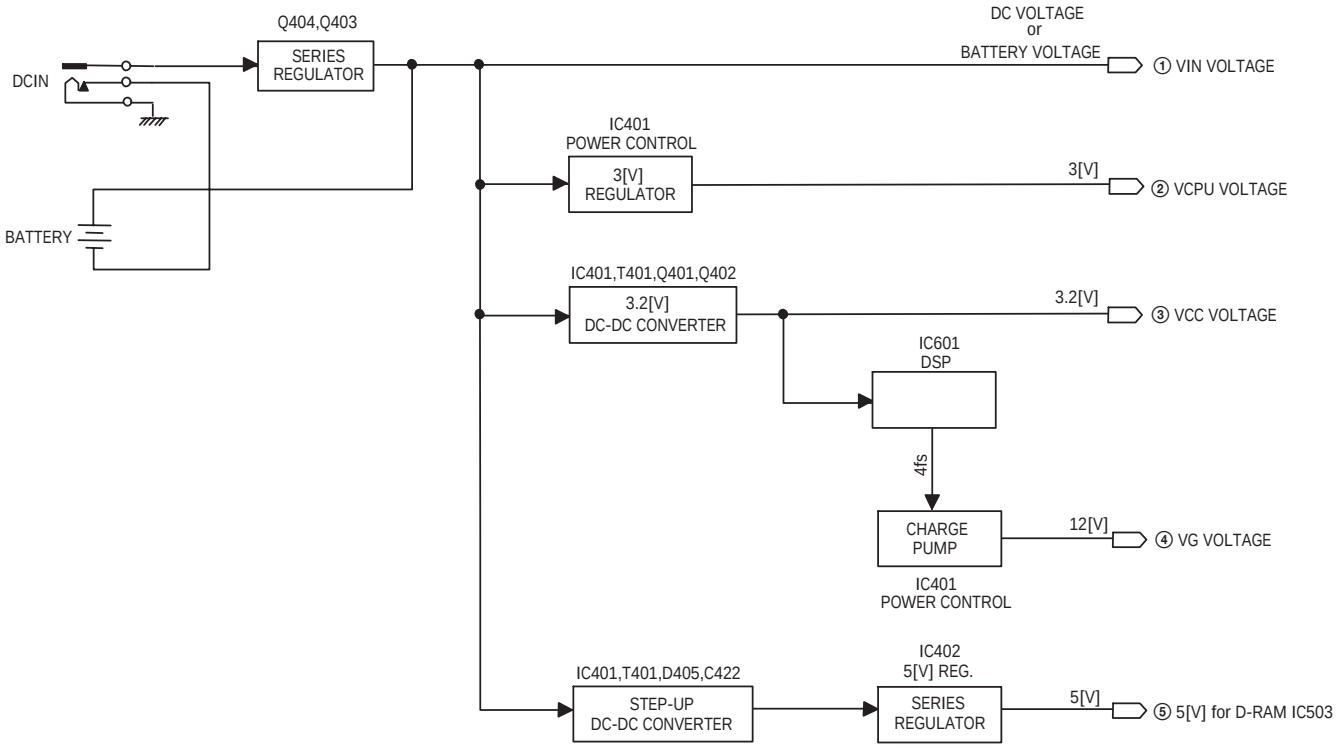



Fig. 4-1 Power supply voltage generation block diagram

During AC adapter drive operation, the following five outputs of the power supply voltage are generated. (Refer to Fig. 4-1.)

① VIN voltage
- The external voltage input to the DC jack is regulated by the SERIES REGULATOR (Q404, Q402), and output as the VIN voltage (approx. 4.5 V).
- When the Discman is operated on battery, the battery terminal voltage is supplied as the VIN voltage.

② VCPU voltage ⟶ "POWER CONTROL IC401"
- This voltage drives the system controller IC801, and is 3.0 V.

③ VCC voltage ⟶ "3.2 V DC-DC CONVERTER (POWER CONTROL IC401, T401, Q401, Q402, etc.)"
- This voltage is used by the RF AMP IC501, DIGITAL SIGNAL PROCESSOR IC601, COIL/MOTOR DRIVE IC701, etc., and is 3.2 V.

④ VG voltage ⟶ "POWER CONTROL IC401"
- This voltage is used by the COIL/MOTOR DRIVE IC701, etc., and is approx. 12 V.

⑤ D-RAM IC503 drive voltage ⟶ "5 V REG. IC402"
- This voltage is used to drive the D-RAM IC503, and is approx. 5.0 V.

Generation of the respective voltages is described below.

### 1. Generation of VIN Voltage

When the DC plug of the AC adapter is connected to the DC jack, the input voltage is regulated by the SERIES REGULATOR (Q404 and Q403), passed through D401 and is output to the POWER CONTROL IC401 and others as the VIN voltage.

## 2. Generation of VCPU Voltage

The VCPU voltage generation circuit block diagram is shown in Fig. 4-2.

### (1) AC adapter drive operation

When the DC plug of the AC adapter is connected to the DC jack, the SERIES REGULATOR (Q404, Q403) is turned on and so the VIN voltage (approx. 4.5 V ) is sent to pin㉚ [VIN] of the POWER CONTROL IC401 via D401, which starts up IC401. The VIN voltage is also sent to pin㉓ [VDO] of the POWER CONTROL IC401 via D404. As the VIN voltage is input to pin㉓ [VDO] of the POWER CONTROL IC401, the VIN voltage is sent to the SERIES REGULATOR inside IC401 which generates the VCPU voltage 3.0 V. The VCPU voltage thus generated is sent from pin⑳ [VCPU] to pin⑫ [VDD] of the system controller IC801 to start up the system controller IC801. The POWER CONTROL IC401 has a built-in step-up/step-down regulator, but the step-up circuit inside IC401 is turned off in AC adapter drive mode.

### (2) Battery drive operation

When the battery is inserted, the battery voltage is sent to pin㉚ [VIN] of the POWER CONTROL IC401 as the VIN voltage to start up IC401. As IC401 starts up, IC401 measures the input voltage at pin㉓ [VDO]. IC401 has a built-in VDO voltage detection circuit. If IC401 detects that the input voltage to pin㉓ [VDO] is less than 3.3 V, the PNM wave is generated by the SYSTEM CONTROLLER section inside IC401 and so the switching waveform is output from pin㉒ [SW]. The input voltage is at all times maintained at 3.3 V or higher by the self step-up operation using the switching output from pin㉒ [SW], L402, D404 and C417. On the other hand, the input voltage to pin㉓ [VDO] of the POWER CONTROL IC401 is sent to the SERIES REGULATOR inside IC401 to generate the VCPU voltage 3.0 V . The VCPU voltage thus generated is sent from pin⑳ [VCPU] to pin⑫ [VDD] of the system controller IC801 to start up IC801. The step-up circuit inside IC401 operates only when a Discman is in the STOP mode. When a Discman is in a mode other than the STOP mode, the VCC generator circuit, which is discussed later, starts operation and outputs the switching waveform from pin㉙ [VOUT1] of the POWER CONTROLLER IC401. The voltage 3.3 V or higher (approx. 3.8 V when the battery voltage is 3 V) is generated by the step-up circuit consisting of the switching output from pin㉙ [VOUT1] of IC401, Q402, T401, D407 and C417. The stepped-up voltage is sent to pin㉓ [VDO] of the POWER CONTROL IC401 which stops operation of the step-up circuit inside IC401. When the Discman runs on battery, the stepped-up voltage that is generated by the above described step-up circuit is sent to pin㉓ [VDO] of the POWER CONTROL IC401 so that the current consumption is suppressed by shorting the on period of the step-up circuit inside IC401.

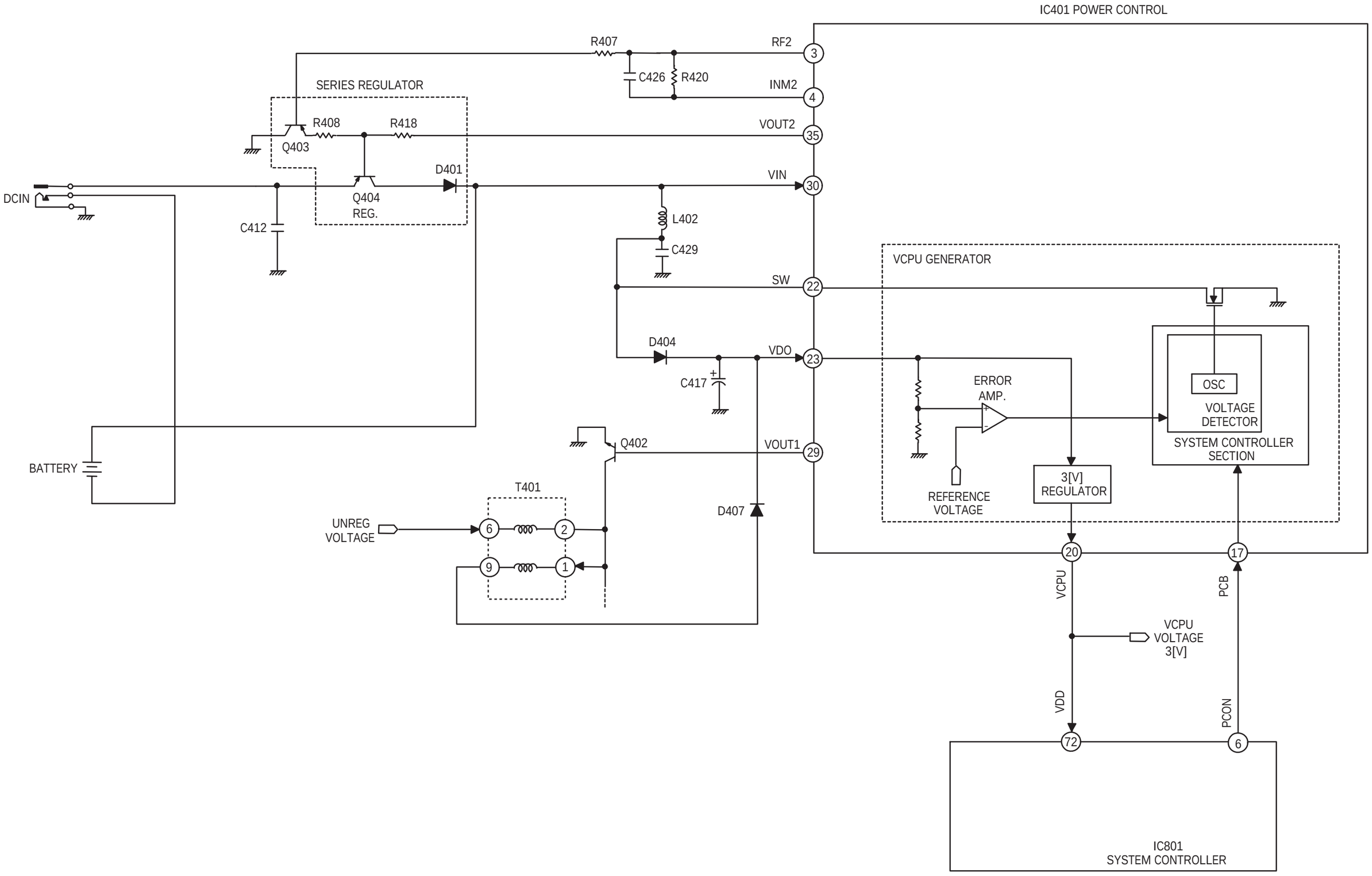



Fig. 4-2 VCPU voltage generation circuit block diagram

## 3. Generation of VCC Voltage

Fig. 4-3 shows the VCC voltage generation circuit block diagram.

### (1) Operation when the operating mode is switched from STOP mode (SLEEP state) to PLAY mode

When either the PLAY key of the Discman or the PLAY key or the FF key or the REW key of the remote control is pressed, the system controller IC801 outputs the "L" signal from pin⑥ [PCON]. When "L" is output, the SYSTEM CONTROLLER section inside IC401 starts its internal operation. As the SYSTEM CONTROLLER section starts internal operation, the PWM waveform that is generated by the PWM comparator inside IC401, is output from pin㉙ [VOUT1] of the POWER CONTROL IC401. As the PWM waveform is output from pin㉙ [VOUT1] of IC401, Q402 and Q401 start the switching operation which starts up the STEP-UP/DOWN DC-DC CONVERTER that generates 3.2 V. The switching output from Q401 is smoothed out by C403 and is divided by the voltage-divider resistors of R401, R402, and R421. The output voltage from the voltage-divider resistors is fed back to pin⑦ [INP1] of IC401. Based on this feedback voltage, IC401 controls the duty ratio of the PWM waveform that is generated by the PWM comparator, in order to control the output voltage. The switching output from Q401 is at the same time smoothed out by L401 and C402 to generate the VCC voltage (3.2 V). As the VCC voltage is generated, the DSP IC601 starts up so that the 4fs signal is sent to pin⑯ [SYNC] of the POWER CONTROL IC401. As the 4fs signal is input to IC401, the SYSTEM CONTROLLER section inside IC401 switches the operation clock to the input 4fs signal from internal oscillation to excuse its operation.

### (2) Operation when the operating mode is switched from PLAY mode to STOP mode (SLEEP state)

When either the STOP key of the Discman or that of the remote control is pressed, the system controller IC801 outputs the "H" signal from pin⑥ [PCON]. This "H" signal stops the PWM output from pin㉙ [VOUT1] of the POWER CONTROL IC401 which outputs the "L" signal. This "L" output turns off Q402 and Q401 and stops outputting the VCC voltage. As the VCC voltage is stopped, the 4fs signal is no longer input to pin⑯ [SYNC] of the POWER CONTROL IC401. When the SYSTEM CONTROLLER section inside IC401 detects that the input to pin⑰ [PCB] goes "H", it stops its internal operation. Note that when the RESUME function is turned off, the system controller IC801 moves the optical pickup to the innermost circumference, and sets the output from pin⑥ [PCON] to "H". When the RESUME function is turned on, the optical pickup is not moved to the innermost circumference.

The waveform timing chart during generation of the VCC voltage is shown in Fig. 4-4.

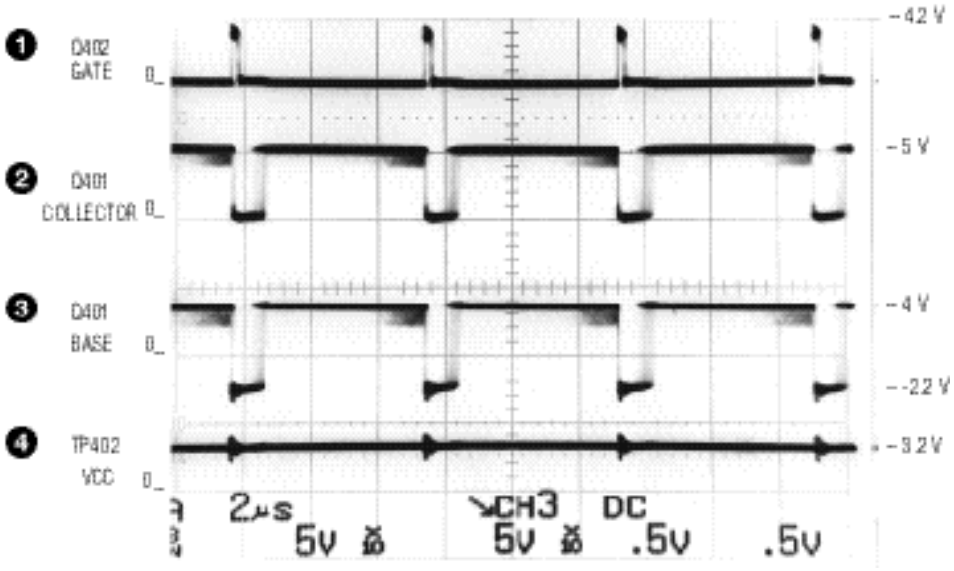



Fig. 4-4 Waveform timing chart during generation of the VCC voltage

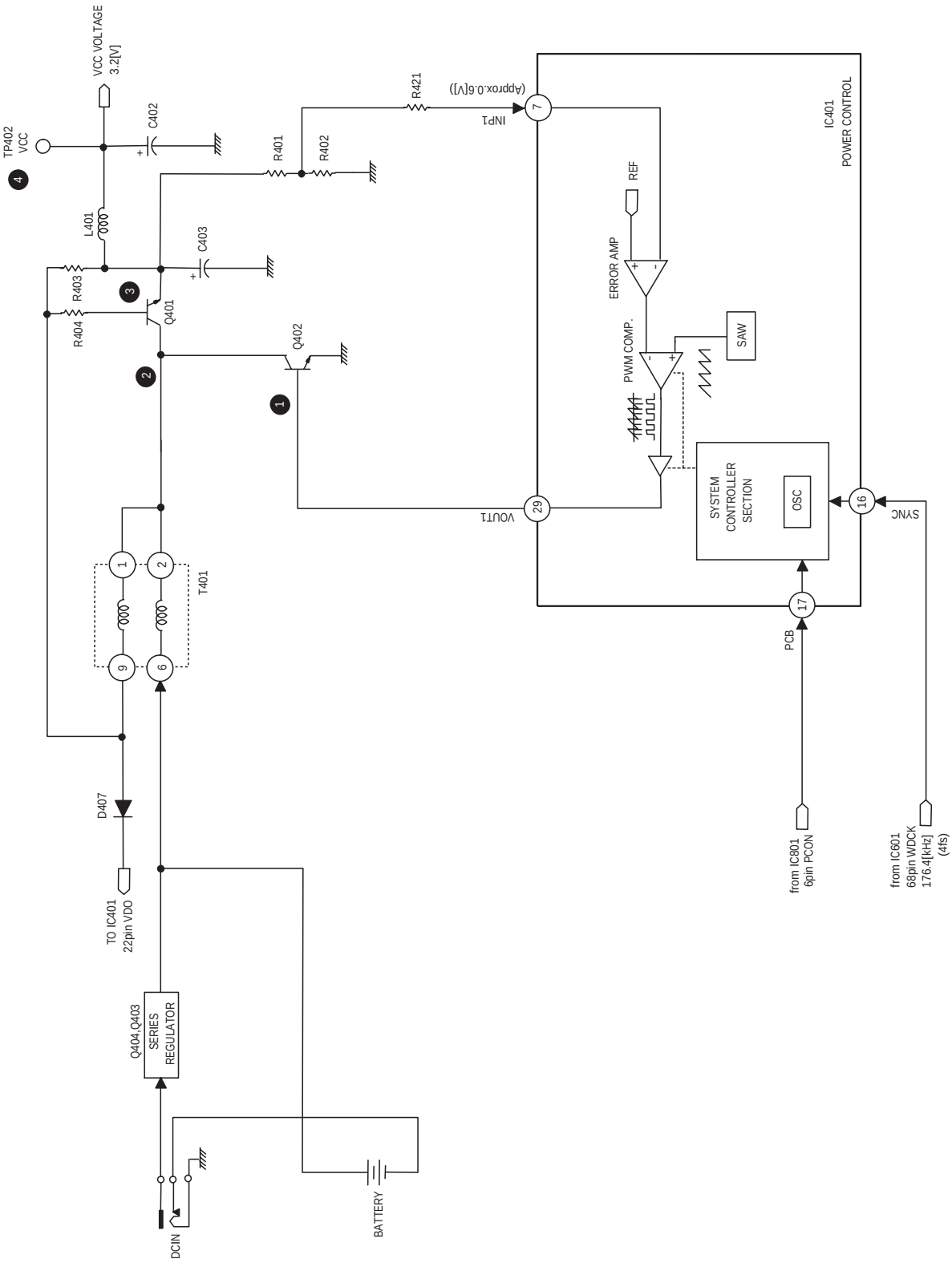



Fig. 4-3 VCC voltage generation circuit block diagram

## 4. Generation of VG voltage

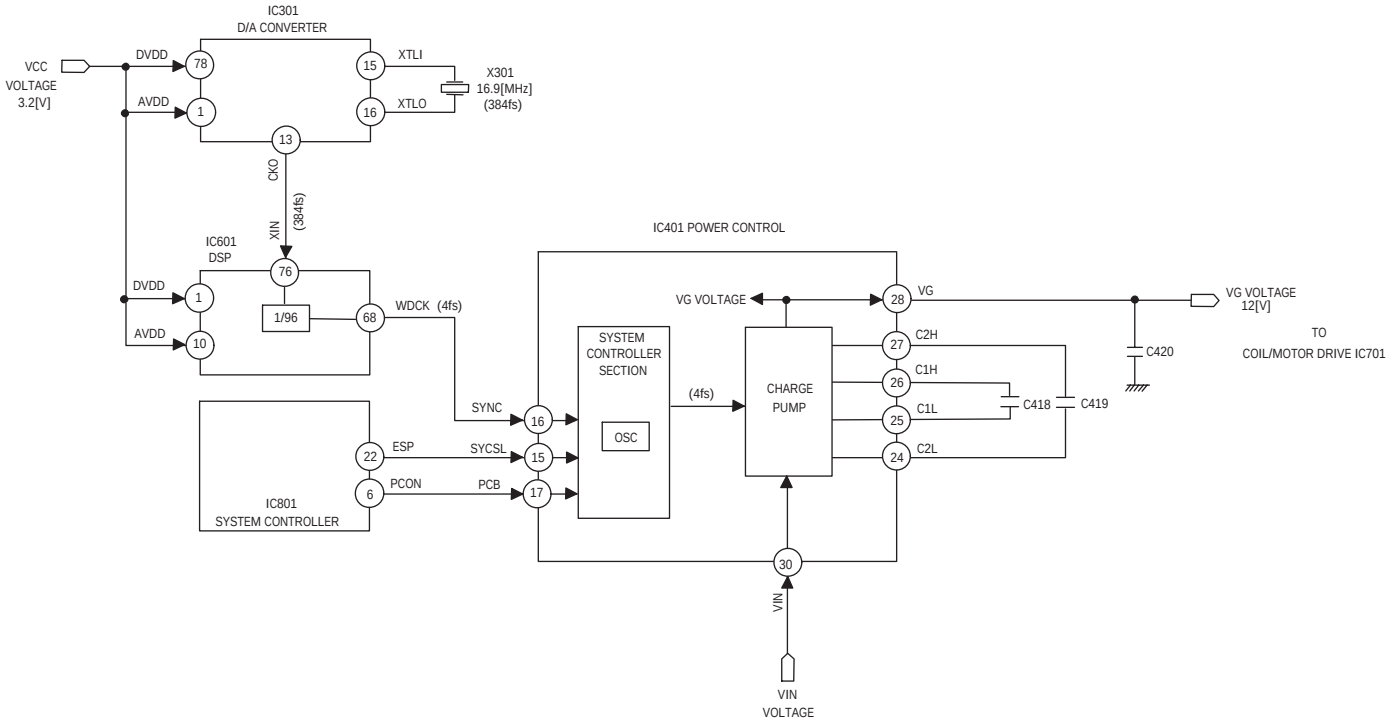



Fig. 4-5 VG voltage generation circuit block diagram

Figure 4-5 shows the VG voltage generation circuit block diagram.
As the VCC voltage 3.2 V is generated as shown, the D/A CONVERTER IC301 starts up. As IC301 starts up, X301 starts oscillating. Then, the 384fs (16.9 [MHz]) signal is supplied to pin⑯ [XIN] of IC601 as the master clock of the DSP IC601 from pin⑬ [CKO] of IC301. Next, when the DSP IC601 starts up, 4fs (176.4[kHz]) signal is generated from the 384fs signal that is input to pin⑯ [XIN] using the frequency-divider inside IC601. Then the 4fs (176.4 [kHz]) signal is output from pin⑱ [WDCK] to pin⑯ [SYNC] of the POWER CONTROL IC401. When the 4fs signal is input to the system controller section inside the POWER CONTROL IC401, the system controller section switches the operation clock to the input 4fs signal from internal oscillation. As the 4fs signal is input to the CHARGE PUMP circuit, the CHARGE PUMP circuit starts functioning*4-2 and the VG voltage (approx. 12 V) is generated. The VG voltage thus generated, is output from pin㉘ [VG] of to the COIL/MOTOR DRIVE IC701. This VG voltage is also used for internal operation of IC401.

*4-2: The 4fs signal is the signal for synchronization and has nothing to do with the operation of CHARGE PUMP.

## 5. Generation of the D-RAM IC503 drive voltage

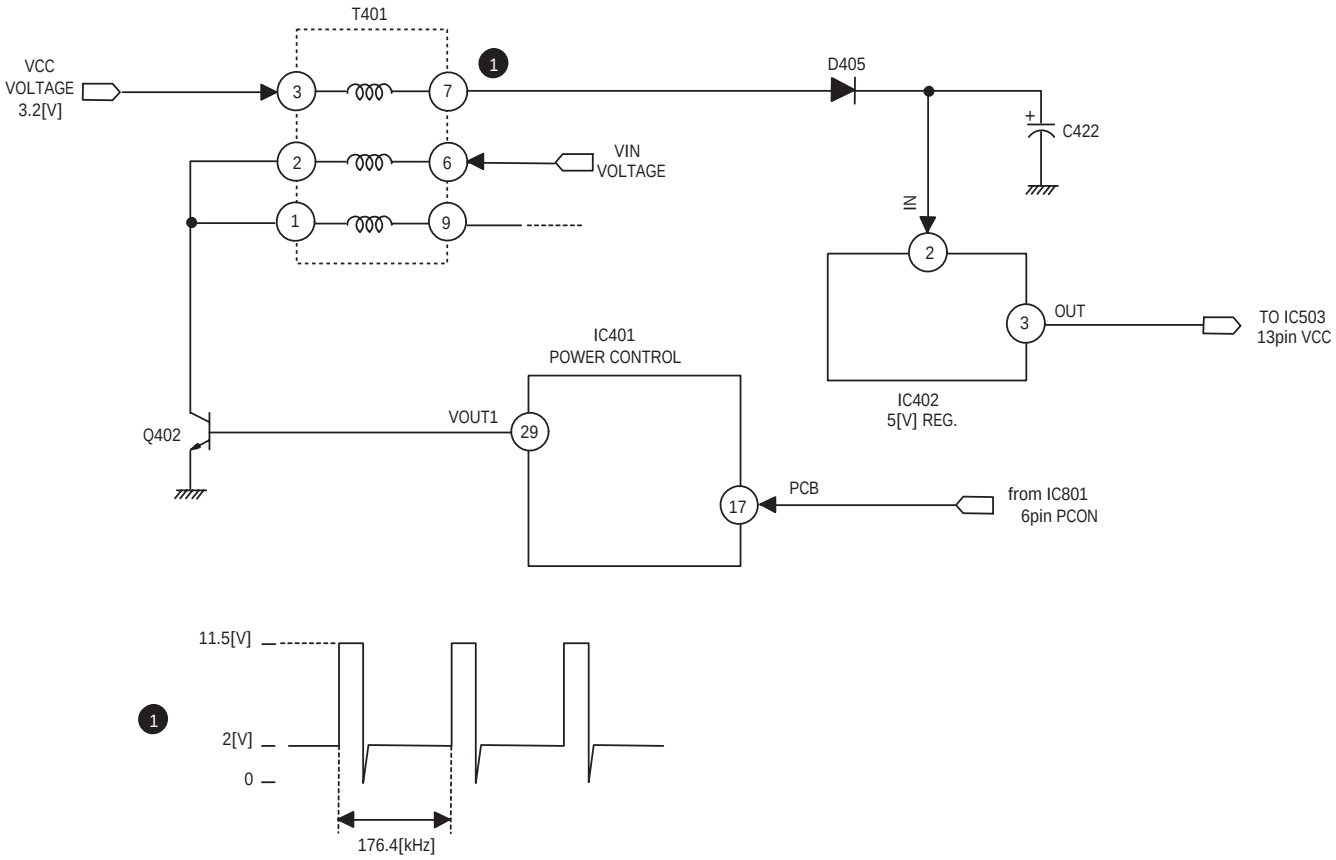



Fig. 4-6 D-RAM IC503 drive voltage generation circuit block diagram

The D-RAM IC503 drive voltage generation circuit block diagram is shown in Fig. 4-6. When the PLAY key is pressed, the system controller IC801 outputs the "L" signal from pin⑥ [PCON]. When "L" is output, the system controller section inside the POWER CONTROL IC401 starts up and outputs the switching waveform from pin㉙ [VOUT1] of IC401. As the switching waveform is output from pin㉙ [VOUT1] of IC401, the STEP-UP DC-DC CONVERTER consisting of Q402, T401, D405, C422 and the output switching waveform, starts and generates the stepped-up voltage (approx. 11 V during AC adapter drive operation) from the above described VCC voltage. The stepped-up voltage thus generated is sent to pin② [IN] of the 5 V REG. IC402. As the 5 V REG. IC402 starts up, +5 V is generated by the series regulator inside IC402. The +5 V regulated power is output from pin③ [OUT] to pin⑬ [VCC] of the D-RAM IC503 as the voltage to drive the D-RAM IC503.

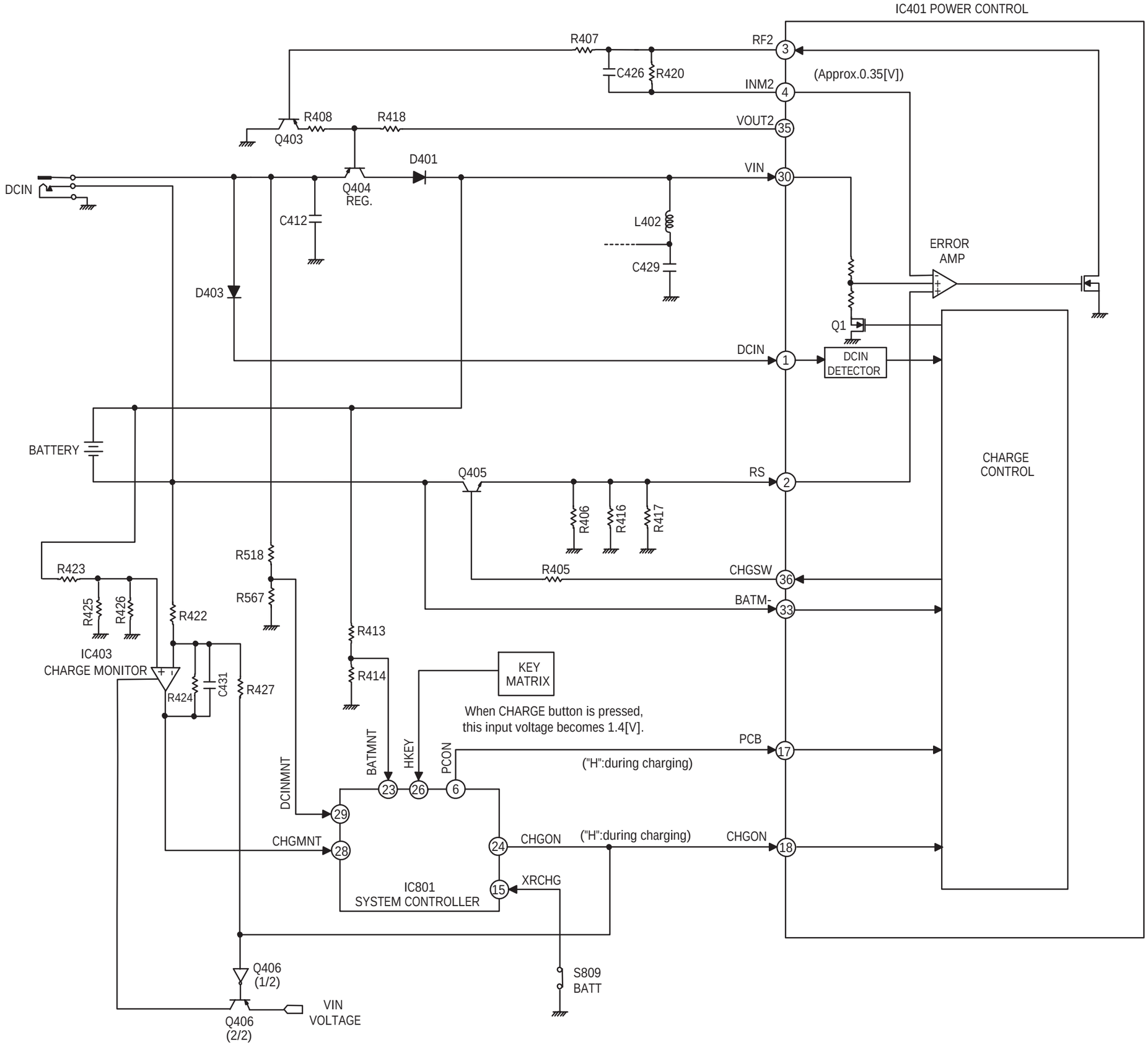



Fig.4-7 Charging circuit block diagram

## 4-4. Charging Circuit

Figure 4-7 shows the charging circuit block diagram.

### (1) Operation of the system controller IC801 during charging

When the DC plug is connected to the DC jack, the VCPU voltage 3 V is generated by the POWER CONTROL IC401, and is sent to the system controller IC801 so that it starts up. When the system controller IC801 starts up, the system controller IC801 detects if the Discman satisfies the following charging conditions or not. After the system controller IC801 recognizes that the following conditions are satisfied, it outputs the "H" signal from pin㉔ [CHGON]. The charging circuit inside the POWER CONTROL IC401 starts the charging operation by this "H" signal. At the same time, Q406(1/2) and Q406 (2/2) are turned on by this "H" signal so that the VIN voltage is sent to the CHARGE MONITOR IC403 which starts the monitoring circuit of the charge voltage.

♦ Charging conditions

1. The Discman operates on DC (output from AC adapter) ⟶ pin㉙ [DCINMNT] of system controller IC801: "H"
2. The rechargeable battery (BP-DM10) is inserted in the Discman ⟶ pin⑮ [XRCHG] of system controller IC801: "L"
3. The Discman is in the STOP state ⟶ pin⑥ [PCON] of system controller IC801 outputs the "H" signal.
4. The CHARGE button is pressed ⟶ Input voltage to pin㉖ [HKEY] of the system controller IC801 is 1.4 V.

### (2) Operation of POWER CONTROL IC401 when charging

POWER CONTROL IC401 contains the CHARGE CONTROL block which starts charging when the charging conditions shown in Table 4-2 are satisfied. When IC401 starts charging, IC401 outputs the "H" signal from pin㊱ [CHGSW]. This "H" signal turns Q405 on. At the same time, IC401 outputs the "H" signal inside IC401 to turn on the N-channel MOS FET Q1. As Q405 is turned on, the voltage that is obtained by I-V converting the current flowing through the rechargeable battery with external resistors R406, R416 to R417, is input to pin② [RS] of IC401. IC401 keeps the current that flows through the rechargeable battery constant at all times by comparing the input voltage at pin② [RS] with the internal reference voltage (0.35 V) with the ERROR AMP.

Table. 4-2 Charging conditions

| | Input | | | Output |
|---|---|---|---|---|
| | Pin ①[DCIN] | Pin ⑰[PCB] | Pin ⑱[CHGON] | Pin ㊱[CHGSW] |
| During charging | H | H | H | H |

### (3) Operation when stopping charging

During charging, the system controller IC801 detects a –Δ V (minus delta V potential) by monitoring the voltages that are input to pin㉘ [CHGMNT]. When the system controller IC801 detects a –Δ V, it stops charging by setting pin㉔ [CHGON] to "L". In addition to the –Δ V detection system, the system controller IC801 uses the timer system (timer of approx. two hours) at the same time in order to stop charging.

# 5. APPENDIX: TYPES AND APPLICATIONS OF SECONDARY BATTERIES FOR PORTABLE EQUIPMENT (RECHARGEABLE BATTERIES)

The nickel-cadmium rechargeable battery is usually used as the secondary battery for portable equipment. Remarkable improvements in energy density in recent years together with the increasing diversification and popularity of portable equipment requiring compact rechargeable batteries, have led to the development of new rechargeable batteries such as the nickel-hydrogen rechargeable battery and lithium-ion secondary battery, and these batteries are starting to be used in large quantities. This section describes the basic theory of the following three types of rechargeable batteries that are widely used in the Discman and MD WALKMAN.

- Nickel-cadmium rechargeable battery
- Nickel-hydrogen rechargeable battery
- Lithium-ion secondary battery

## 5-1. Nickel-Cadmium Rechargeable Battery

The sealed type nickel-cadmium rechargeable battery for consumer use is widely used in compact electronic equipment because it has the following features:

- The discharge voltage characteristics are flat.
- Boosting charge is possible.
- It has a long life.
- It withstands over-charging and over-discharging.
- It has a low internal resistance, making possible a high rate discharge (large current discharge).
- It has high mechanical strength thanks to its metallic case.
- It suffers little deterioration even after a long period of storage.

### 1. Types of Batteries

Sealed type nickel-cadmium rechargeable batteries come in cylindrical, square and button shapes for the various applications. This section describes the cylindrical and square nickel-cadmium rechargeable batteries.

#### (a) Cylindrical battery (KR)

The cylindrical nickel-cadmium rechargeable battery is the most widely used. Some that have the same dimensions as dry cell batteries are now also on the market. The many applications include the power supply for portable electronic equipment, electric tools that require a fast discharge performance, emergency lights, guidepath lights, etc. The structure of the cylindrical nickel-cadmium rechargeable battery is shown in Fig. 5-1; a positive electrode and a negative electrode are rolled in a spiral with a separator between the electrodes and are housed in a metal case. The cylindrical nickel-cadmium rechargeable battery has a built-in reset type safety valve, so even if the internal pressure of the battery increases due to over-charging with a large current, gas is released through the valve to prevent the battery from breakage. Figure 5-2 shows the structure of a typical safety valve.

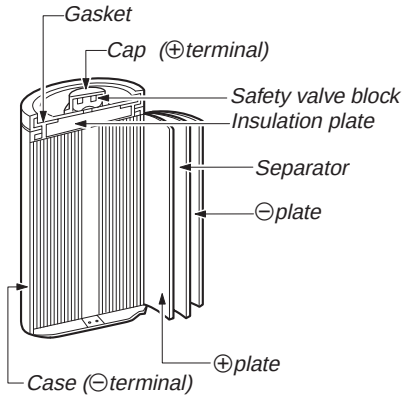



Fig. 5-1 Structure of cylindrical nickel-cadmium rechargeable battery

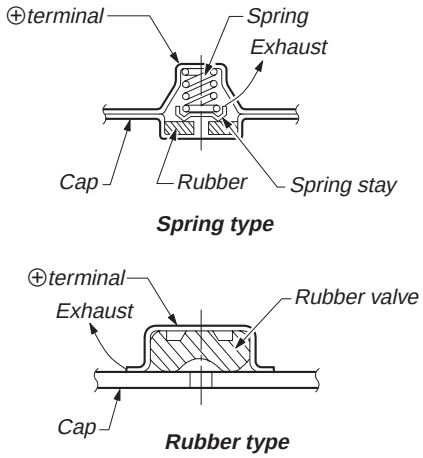



Fig. 5-2 Structure of safety valve

**(b) Square battery (GP)**

The square nickel-cadmium rechargeable battery was developed by Japan Storage Battery Co., Ltd. in 1985 for the first time in the world, and is used in the Sony headphone stereo-cassette tape player. Its shape means that space is not wasted, and so as demand for more compact, thin portable electronic equipment has increased, so too has demand for this battery. Applications include compact Audio & Visual equipment including the headphone stereo-cassette tape player, and communication equipment such as cellular phones. The structure of the battery is shown in Fig. 5-2; strips of positive plate and negative plate are stacked with a separator between them, and are encased in a metallic deep-drawn case. It has a built-in ultra-small safety valve that is just 3.6 mm wide to keep the battery thin.

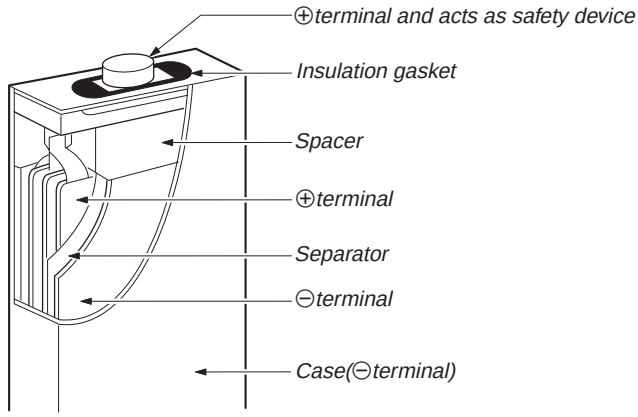



Fig. 5-3 Structure of square nickel-cadmium rechargeable battery

**2. Characteristics of Nickel-Cadmium Rechargeable Battery**

**(a) Comparison with dry cell battery**

A comparison of the discharge characteristics between the size AA nickel-cadmium rechargeable battery and dry cell battery is shown in Fig. 5-4. The discharge voltage of the nickel-cadmium rechargeable battery is characterized by a flat discharge curve and a sharp drop at around the end of the discharge period. The capacity of the nickel-cadmium rechargeable battery is being increased, and AA-size batteries capable of delivering 900 mAh are already in practical use.

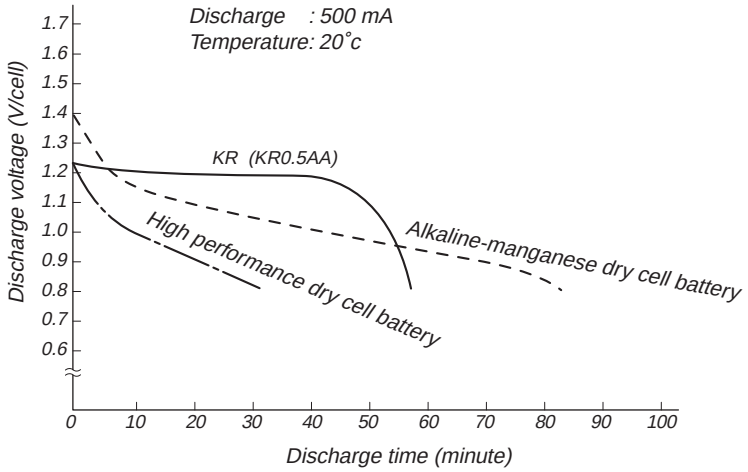



Fig. 5-4 Comparison of discharge characteristics between general-purpose KR battery and dry cell battery

**(b) Charge characteristics**

The nickel-cadmium rechargeable battery is charged by the constant current charge method. The charge characteristics of the general-purpose cylindrical (KR) battery are shown in Fig. 5-5. The standard charge takes 14 to 16 hours with the current of 0.1 CmA as shown in Fig. 5-5, and requires over-charging. Over-charging is necessary because the charge efficiency decreases as oxygen gas is generated at the end of charging at the nickel hydroxide positive electrode. The relation between the charging temperature and discharge capacity is shown in Fig. 5-6. The charging efficiency decreases remarkably as the charging temperature rises and as the charge current decreases. Therefore, an exclusively designed rechargeable battery is used for special applications such as emergency lights, and is charged by a trickle charge. The relation between temperature and the charge-end voltage of the nickel-cadmium rechargeable battery is shown in Fig. 5-7. The figure shows that the charge-end voltage decreases as the temperature during charging is higher. This means that the charge current remarkably changes depending upon temperature when the nickel-cadmium rechargeable battery is charged at a constant voltage. Constant voltage charge must therefore be avoided because it can cause the battery to deteriorate and burnout as an excessive current flows into the battery during charging at a high ambient temperature.

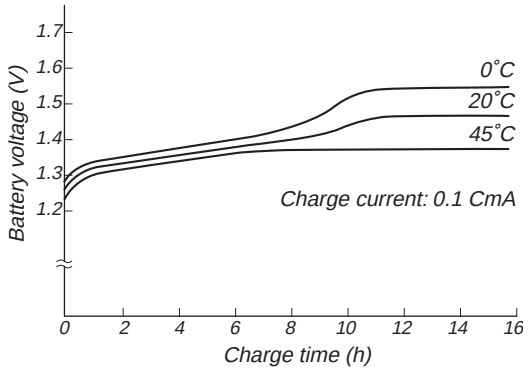



Fig. 5-5 Standard charge characteristics of general-purpose KR battery

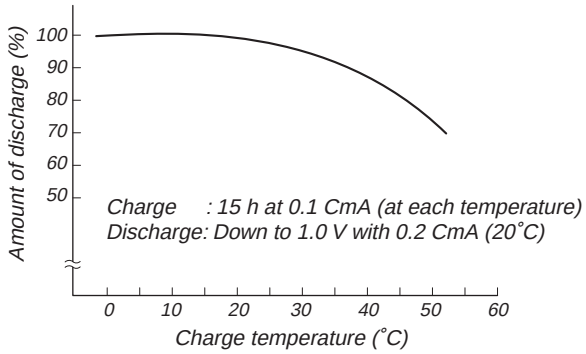



Fig. 5-6 Relation between charge temperature and amount of discharge of general-purpose KR battery

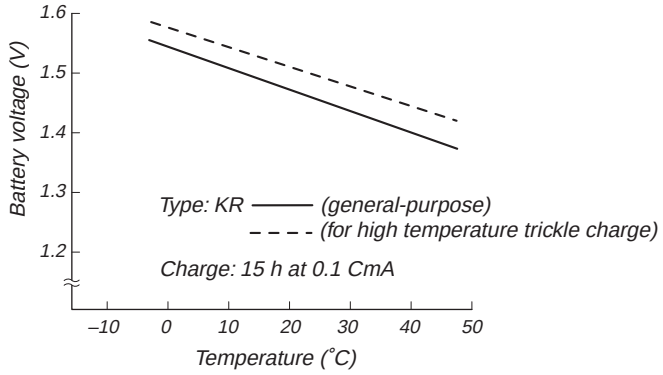



Fig. 5-7 Relation between temperature and charge-end voltage of KR battery

### (c) Discharge characteristics

The discharge capacity (service capacity[*5-1]) of the nickel-cadmium rechargeable battery changes depending upon the discharge current and temperature. However, their effects are smaller compared with the dry cell battery and lead rechargeable battery. The discharge characteristics of the KR battery at the respective discharge currents are shown in Fig. 5-8. The continuous discharge of 3 to 5 CmA is possible as shown in the figure.

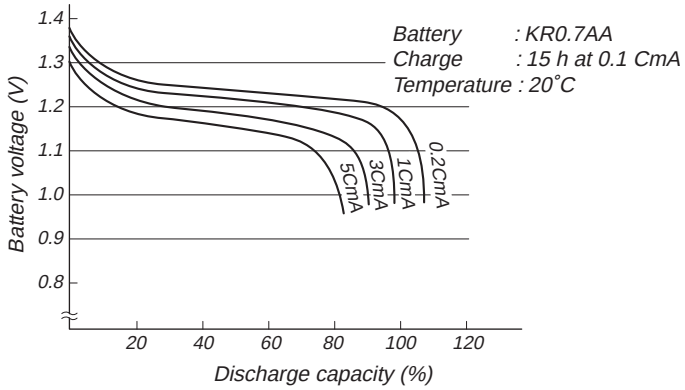



Fig. 5-8 Discharge characteristics of general-purpose KR battery at various discharge currents

The temperature dependence of the discharge capacity of the KR battery is shown in Fig. 5-9. The discharge capacity decreases at the low temperature of 0˚C or below, but discharge is possible over the wide temperature range of -20 to +60˚C.

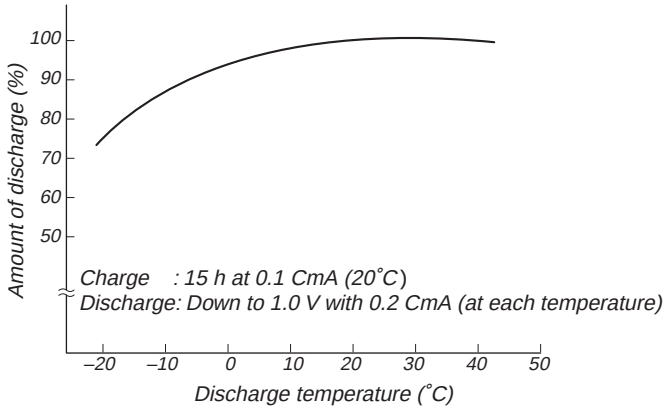



Fig. 5-9 Relation between discharge temperature and amount of discharge of general-purpose KR battery

♦ **Charge-discharge coefficient "C"**

The value "C" that indicates the hour-rate is frequently used when describing the charge-discharge characteristics. The value "C" is called the charge-discharge coefficient. The current of one-C (one-hour rate) (in ampere) is that which is required to discharge a battery for one hour, or to charge a battery for one hour. Put simply, when using a battery having a capacity of 10 Ah, discharging the battery at 10 A is called "a battery discharged at 1C". When the battery is discharged at 1 A, it is called "a battery discharged at 0.1C."

* 5-1: The terminology "discharge capacity" of a battery is sometimes called "service capacity" of a battery.

**(d) Capacity storage characteristics**

The residual discharge capacity of the KR battery that is measured after full charging and storage at various temperatures, is shown in Fig. 5-10. The amount of self-discharge of the nickel-cadmium rechargeable battery is larger than that of the dry cell battery and lead rechargeable battery. The amount of self-discharge increases as the temperature rises.

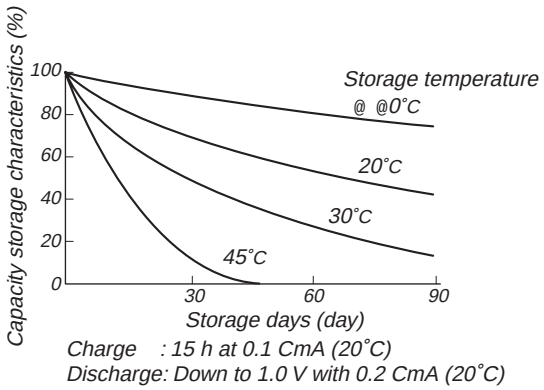



Fig. 5-10 Capacity storage characteristics of general-purpose KR battery

**(e) Life characteristics**

When describing the life of the nickel-cadmium rechargeable battery, the conditions for measurement are specified by the IEC specifications and the JIS standards. An example of the cycle life characteristics is shown in Fig. 5-11, which shows that the nickel-cadmium rechargeable battery has an excellent life of 1000 cycles or more. However, this is the result under specific conditions, and the life greatly changes depending upon the operating conditions and other factors. The main causes that affect life are the following.

(1) Temperature: The optimum operating conditions of the nickel-cadmium rechargeable battery are normal room temperature. Deterioration of the battery is accelerated if the battery is continuously used under a high temperature exceeding 40˚C.

(2) Depth of discharge: Depth of discharge affects the cycle life. When deep discharge is repeated, the cycle life is shortened. The relation between the depth of discharge and the cycle life of the general-purpose KR battery is shown in Fig. 5-12.

(3) Over-charge and over-discharge: When a nickel-cadmium rechargeable battery is over-charged or over-discharged, the internal pressure of the battery increases, gas is exhausted from the safety valve, the electrolyte decreases, and hence deterioration of the battery is accelerated.

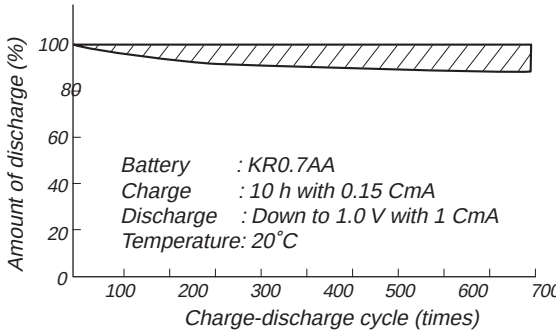



Fig. 5-11 Example of cycle life of general-purpose KR battery

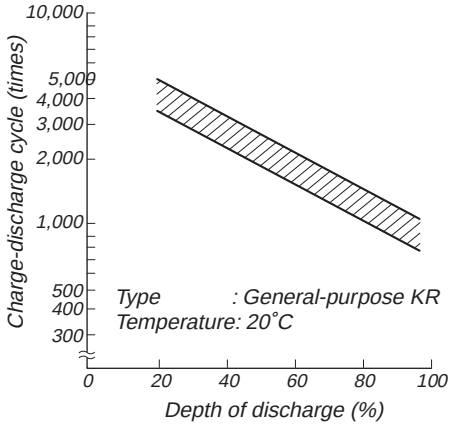
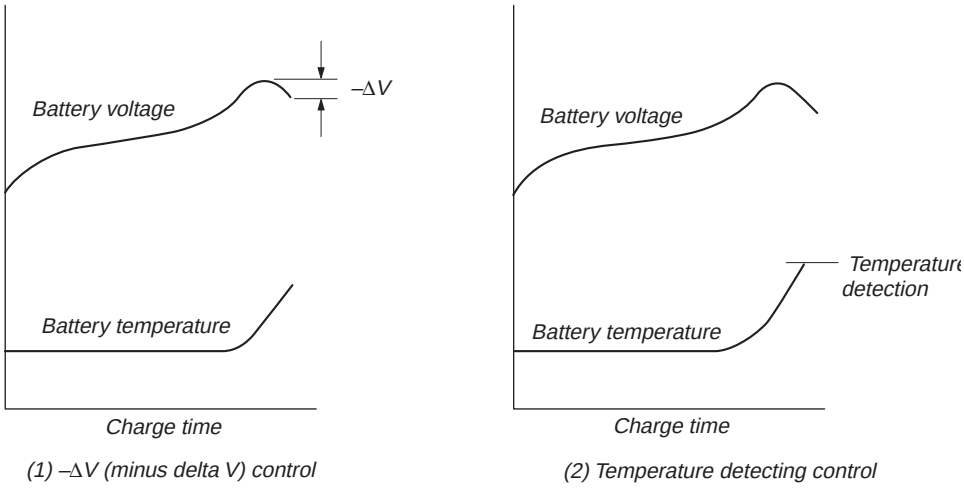



Fig. 5-12 Relation between depth of discharge and cycle life of general-purpose KR battery

**(f) Boosting charge**

Several methods of boosting charge are used for nickel–cadmium rechargeable batteries. However, the methods of controlling the boosting charge are classified into two main types: (1) Method of detecting the battery voltage, and (2) Method of detecting the battery temperature. Examples of actual systems are shown in Fig. 5–13. The –ΔV (minus delta V) system that detects the voltage drop after fully charged is most widely used. In the sealed–type nickel–cadmium rechargeable battery, the battery voltage reaches its peak at the charge–end, then decreases as the battery temperature rises due to oxygen gas absorption reaction of the negative electrode. This characteristic performance of the battery is detected and used to control charging, which is called the –ΔV (minus delta V) system. This system is very reliable; over–charging of batteries is small and mis–operation is unlikely.




*(1) –ΔV (minus delta V) control* *(2) Temperature detecting control*

Fig. 5-13 Boosting charge system for sealed-type nickel-cadmium rechargeable battery

The cycle life characteristics of the nickel-cadmium rechargeable battery using the boosting charge are shown in Fig. 5-14. Even the square nickel-cadmium rechargeable battery has a performance of 500 cycles or more for its charge-discharge characteristics as shown in the figure.

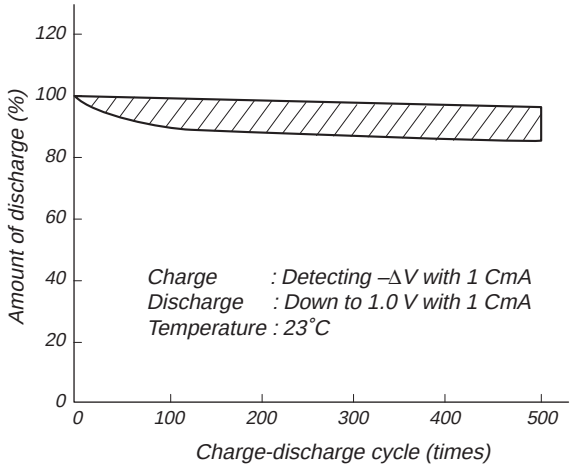



Fig. 5-14 Example of cycle life of the GP6E type battery using the boosting charge

**(g) Memory effect**

The battery voltage of the nickel-cadmium rechargeable battery can decrease in two steps when it is deeply discharged after shallow charge-discharge is repeated or after trickle charging for many hours. This phenomenon is generally called the memory effect, and can easily occur when the cut-off voltage of the load equipment is set to 1.1 V/cell or higher. However, this phenomenon is a temporary one, and can be removed by deep discharging once or twice.

## 5-2. Nickel-Hydrogen Rechargeable Battery

The nickel-hydrogen rechargeable battery (abbreviation: Ni-MH) is a rechargeable battery using nickel oxide as the positive electrode and a hydrogen occluded alloy as the negative electrode.Square, cylindrical and button shaped nickel-hydrogen rechargeable batteries having similar shapes to those of the sealed-type nickel-cadmium rechargeable battery (referred to as "nickel-cadmium rechargeable battery" hereafter), which are widely used in many types of equipment, are now on the market. The voltage characteristics of the nickel-hydrogen rechargeable battery are similar to those of the nickel-cadmium rechargeable battery. The square nickel-hydrogen rechargeable battery is outlined below.

### 1. Outside Appearance and Applications

Nickel-hydrogen rechargeable batteries are available in both cylindrical and square types like the nickel-cadmium rechargeable battery, and the outside appearances are also similar. A comparison of various specifications between the square nickel-hydrogen rechargeable battery "HP series" and the conventional square nickel-cadmium rechargeable battery "GP series" is shown in Table 5-1. Comparing batteries of the same dimensions, we can see that the volumetric energy density is 38% to 65% higher in the HP series, and is 15% to 40% better than the high capacity type GPN series. Utilizing these characteristics, the nickel-hydrogen rechargeable battery can be used for many more applications to supply power for various portable equipment such as compact notebook personal computers and other office automation equipment, as well as in compact communication equipment such as cellular phones.

Table 5-1 Comparison of specifications between the square nickel-hydrogen rechargeable battery "HP series" and conventional square nickel-cadmium rechargeable battery "GP series"

| Name of battery | Model name | Nominal voltage [V] | Rated capacity [mAh] | Dimensions [mm] | | | Mass [g] | Energy density | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total height | Width | Thickness | | Volume [Wh/l] | Mass [Wh/kg] |
| Nickel-hydrogen rechargeable battery | HP6 | 1.2 | 560 | 47.6 | 16.4 | 5.6 | 17.0 | 154 | 39.5 |
| | HP9 | | 850 | 66.3 | 16.4 | 5.6 | 24.0 | 167 | 42.5 |
| | HP10 | | 940 | 66.3 | 16.4 | 5.6 | 24.2 | 185 | 46.6 |
| | HP9CM | | 850 | 47.6 | 16.4 | 7.8 | 23.0 | 166 | 44.3 |
| Nickel-cadmium rechargeable battery | GP4E | 1.2 | 380 | 47.6 | 16.4 | 5.6 | 16.5 | 104 | 27.6 |
| | GP6E | | 570 | 66.3 | 16.4 | 5.6 | 23.5 | 112 | 29.1 |
| | GP6CM | | 580 | 47.6 | 16.4 | 7.8 | 22.0 | 114 | 31.6 |
| | GP9E | | 850 | 66.3 | 16.4 | 7.8 | 31.5 | 120 | 32.4 |
| Nickel-cadmium rechargeable battery (high capacity type) | GPN4US | 1.2 | 380 | 39.6 | 16.2 | 5.6 | 12.5 | 127 | 36.5 |
| | GPN5CS | | 480 | 47.6 | 16.4 | 5.6 | 15.5 | 132 | 37.2 |
| | GPN7CM | | 730 | 47.6 | 16.4 | 7.8 | 20.5 | 144 | 42.7 |

Note 1: Dimensions are the maximum values without insulation tubes.
Note 2: HP10 is the product for stereo headphones.

## 2. Charge-Discharge Characteristics

The charge characteristics of the square nickel-hydrogen rechargeable battery at various charge currents are shown in Fig. 5-15, and the temperature characteristics at the charge current of 1 CmA are shown in Fig. 5-16. The behavior of the charge voltage of the square nickel-hydrogen rechargeable battery is quite similar to that of the nickel-cadmium rechargeable battery. The discharge characteristics at the respective discharge currents are shown in Fig. 5-17. Comparing the discharge characteristics at the 2 CmA current with those at the 0.2 CmA as shown in the figure, the midpoint voltage during discharging decreases about 100 mV, but the discharge capacity down to 1.0 V decreases only by about 10%. The discharge characteristics at large discharge currents are equivalent to those of the nickel-cadmium rechargeable battery. The temperature characteristics when discharging at 1 CmA are shown in Fig. 5-18, showing that stable capacity is obtained over the wide temperature range of 0 to +40˚C.

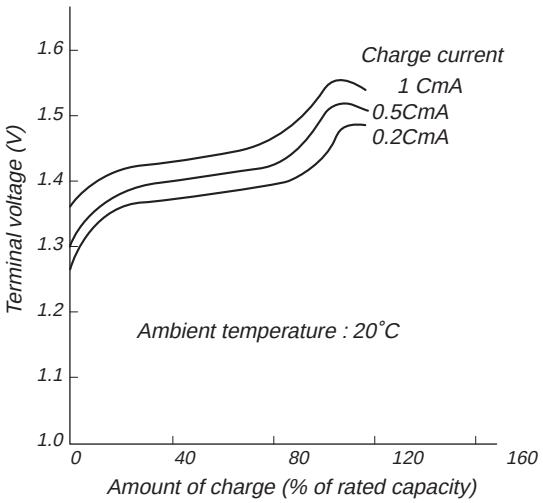



Fig. 5-15 Charge characteristics at the respective charge current of the HP battery

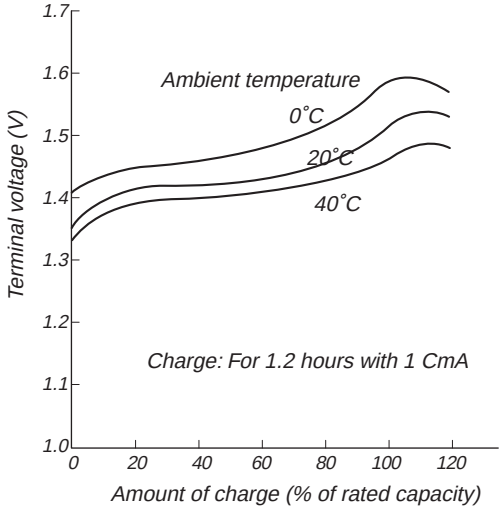



Fig. 5-16 Charging temperature characteristics of HP battery

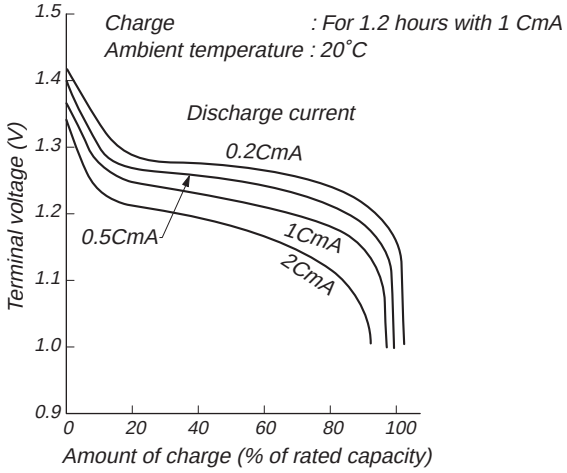



Fig. 5-17 Discharge characteristics at various discharge currents of HP battery

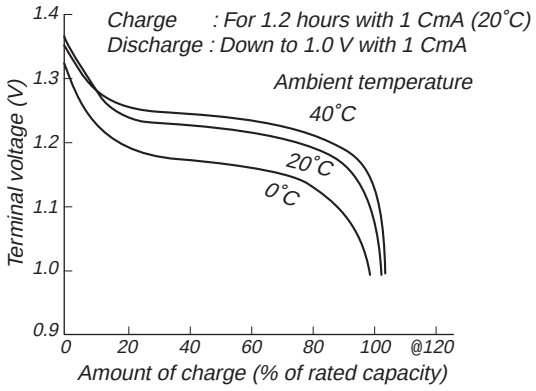



Fig. 5-18 Discharging temperature characteristics of HP battery

### 3. Charge-Discharge Cycle Life Characteristics

The transition of capacity is shown in Fig. 5–19 when the charge–discharge cycle test is performed under the conditions of the 1 CmA charge controlled by –ΔV (10 mV) detection and the discharge limited to 1.0 V with 1 CmA. About 80% or more of the initial capacity is maintained after 500 cycles as shown in the figure, indicating that it has the superior life characteristics.

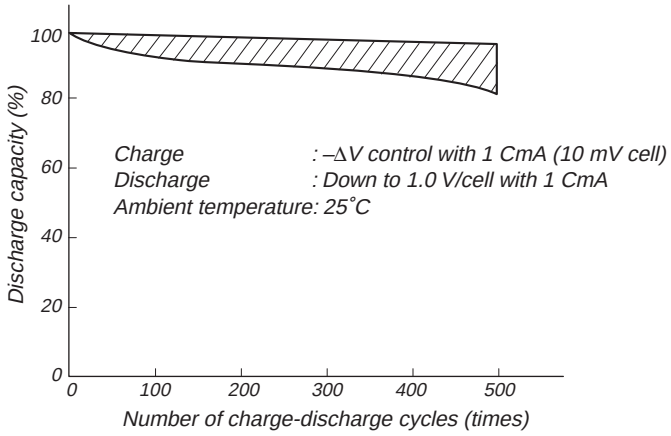



Fig. 5-19 Example of cycle life characteristics of the HP9 battery

### 4. Capacity Storage Characteristics

The capacity storage characteristics of the square nickel-hydrogen rechargeable battery are shown in Fig. 5-20 when it is charged to 120% with 1 CmA at 20˚C, stored at the temperatures of 0˚C, 20˚C and 40˚C, then discharged to 1.0 V/cell at 0.2 CmA at 20˚C. The residual capacity after storage for 30 days at 20˚C is about 70% of the initial value, which is almost equivalent to the value of the conventional nickel-cadmium rechargeable battery GP series.

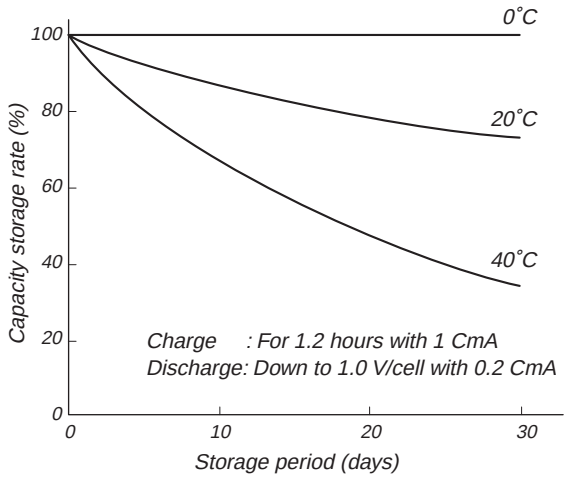



Fig. 5-20 Capacity storage characteristics of HP battery

## 5. Methods of Boosting Charge

Even though the standard charge rate of the nickel–hydrogen rechargeable battery is six hours with 0.2 CmA, the practical trend at present is a boosting charge of around one hour. There are two main types of boosting charge control methods for the nickel–hydrogen rechargeable battery: (1) –Δ V method and (2) the method using the temperature rise of the battery.

♦ –Δ V method

The –Δ V method uses the phenomenon that a battery voltage reaches its peak once, then decreases by the heating that accompanies the oxygen gas absorbing reaction of the negative electrode at the charge–end period. The amount of voltage decrease (–Δ V method) is detected. This method ensures a constant voltage level without being affected by the ambient temperature. However, the amount of voltage decrease (–Δ V method) tends to be smaller in the nickel–hydrogen rechargeable battery than that of the nickel–cadmium rechargeable battery. Therefore, the general practice is to use the –Δ V method as well as another method such as by using the temperature rise of the battery or by using a timer.

♦ Method using the temperature rise of a battery

The method using the temperature rise of the battery detects the size of temperature rise (ΔT) or speed of temperature rise (dT/dt). This method has the advantage that the amount of over–charging is smaller than that of the –Δ V method. However, since it requires temperature detection using a thermistor or other such element, the method is suitable for assembled batteries but not for a single battery that is directly inserted into the battery compartment of an electronic product.

Therefore, ordinary consumer electronic products use both the –Δ V method and the timer method in order to improve the reliability of charge control.

The conceptual diagram of the boosting charge method of the square nickel–hydrogen rechargeable battery is shown in Fig. 5–21. The actual values of boosting charge current of $I_1$ = 1 CmA, trickle charge current of $I_2$ = 0.03 to 0.05 CmA and –Δ V detection value = 5 to 10 mV/cell, are considered to be appropriate. The boosting charge ending timer T (60 to 80 minutes) is required in order to prevent batteries from deterioration due to over–charging if the charge ending period is not detected.

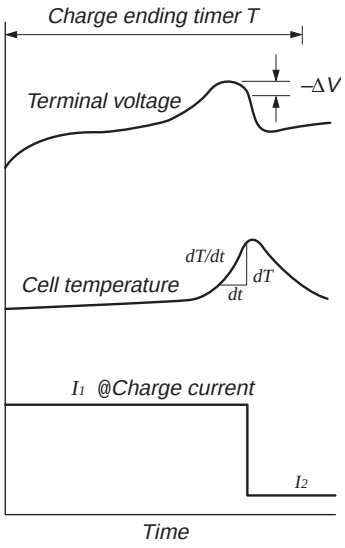



Fig. 5-21 Boosting charge method of HP battery

## 5-3. Lithium-Ion Secondary Battery

The lithium-ion primary battery, with its high capacity and high output voltage in a compact size, is commonly used for memory backup and as the power supply for small electronic devices. However, with the increasing demand for higher performance and longer battery life as portable electronic devices have become more sophisticated, lithium-ion secondary batteries are strongly desired for economy, effective use of resources and environmental conservation since they can be reused. The lithium-ion secondary battery uses, instead of metallic lithium, carbon materials that are occluded lithium-ion at the negative electrode. Because such batteries are free of the problems of metallic lithium, they are expected to be used as the power supply for small electronic devices in future.

### 1. Features of Lithium-Ion Secondary Battery

#### (a) High operating voltage

Though the operating voltage varies depending upon the type of positive electrode used, the operating voltage is typically as high as 3 to 4 volts, which is equivalent to two or three nickel-cadmium rechargeable battery connected in series. This means that the number of cells used in an enclosure can be reduced, and hence the probability of failure is reduced accordingly.

#### (b) High energy density

The energy density is 1.5 to 2 times that of the nickel-cadmium rechargeable battery, so batteries can be made compact and light-weight.

#### (c) Good output characteristics

A current as large as that of the aqueous solution type battery can flow through the external circuit by shortening the distance between the electrodes and by increasing the chemical reacting area of electrodes, even though an organic electrolyte of low conductivity is used. This means that the high capacity lithium-ion secondary battery can power small motors and computer hard disk drives.

#### (d) Excellent safety

The lithium-ion secondary battery is far safer than the conventional metallic lithium battery because the lithium exists in the form of ions and not metallic form.

#### (e) Long cycle life

The battery can withstand more than 500 cycles of repeated charging and discharging. Capacity is hardly diminished even when full-charging and full-discharging are repeated, so the cycle life is excellent.

#### (f) No memory effect

The lithium-ion secondary battery does not show the memory effect that reduces the nominal battery capacity when shallow discharge and recharge are repeated, which occurs due to the property of nickel-cadmium rechargeable batteries. Therefore, there is no need for the refresh-discharge circuit that discharges the remaining power before starting charging to prevent reducing the charging capacity.

#### (g) Quick charging

Charging can be done at a current larger than that of the battery by using metallic lithium for the negative polarity, and the battery can be fully charged within one to several hours.

#### (h) High leakage resistance

The lithium-ion secondary battery has a high leakage resistance compared with conventional batteries using an alkaline electrolyte because an organic electrolyte is used that hardly leaks compared with alkaline electrolyte, and an excellent sealing method is used.

## 2. Types of Batteries

The lithium-ion secondary battery can be classified into: (1) button-type battery for low current applications such as memory backup, (2) cylindrical-type battery, and (3) square-type battery for cyclic applications. The cylindrical and square batteries are outlined below.

### (a) Cylindrical battery

The cylindrical battery has the structure shown in Fig. 5-22. The battery contains spiral strips of positive and negative electrodes that are rolled with a separator in between the electrodes and housed in a metal case before sealing. The shape of the lithium-ion secondary battery looks like a cylindrical nickel-cadmium rechargeable battery, but has special safety features. For example, the built-in PTC element limits the current flow by increasing its resistance to prevent abnormal heating when the external circuit is shorted and a large current flows. Another example is the non-reset type safety valve that operates during abnormality to prevent the battery from explosion due to abnormal increase of inner pressure due to internal shorting or external heating.

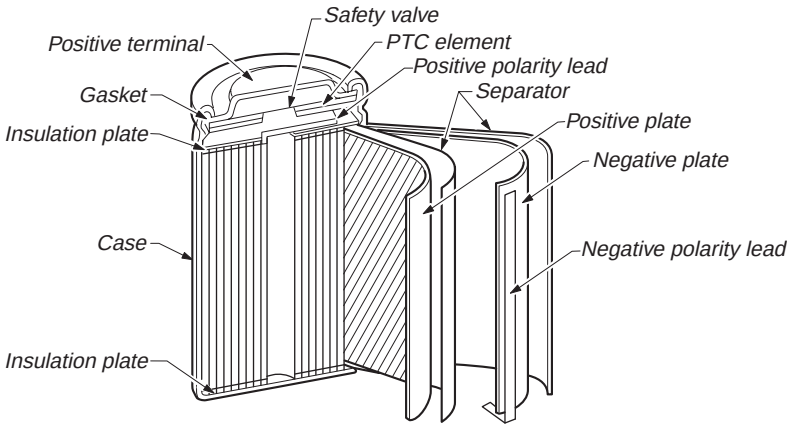



Fig. 5-22 Structure of cylindrical lithium-ion secondary battery

The performance of the typical cylindrical lithium-ion secondary battery is shown in Table 5-2. Applications are portable electronic devices such as cellular phone, notebook personal computer, mini-disc, video camera power supply, etc.

Table 5-2 Performance of cylindrical lithium-ion secondary battery (manufactured by Sony)

| Model | Nominal voltage [V] | Rated capacity [mAh] | Approximate dimensions | | Mass [g] |
|---|---|---|---|---|---|
| | | | Diameter | Height | |
| US14500 | 3.6 | 500 | 14 | 50 | 19 |
| US14650 | 3.6 | 650 | 14 | 65 | 25 |
| US16630 | 3.6 | 850 | 16 | 63 | 29 |
| US17670 | 3.6 | 1200 | 17 | 67 | 36 |
| US18650 | 3.6 | 1350 | 18 | 65 | 40 |
| US20500 | 3.6 | 1300 | 21 | 51 | 40 |
| US26650 | 3.6 | 2700 | 26 | 65 | 83 |

**(b) Square battery**

The cylindrical battery does not use space so efficiently, and its thickness cannot be reduced below a certain level. In response to the need for thinner batteries for compact, slim electronic devices, square batteries were developed. The structure of the square lithium-ion secondary battery is shown in Fig. 5-23; it has almost the same internal structure as that of the cylindrical battery.

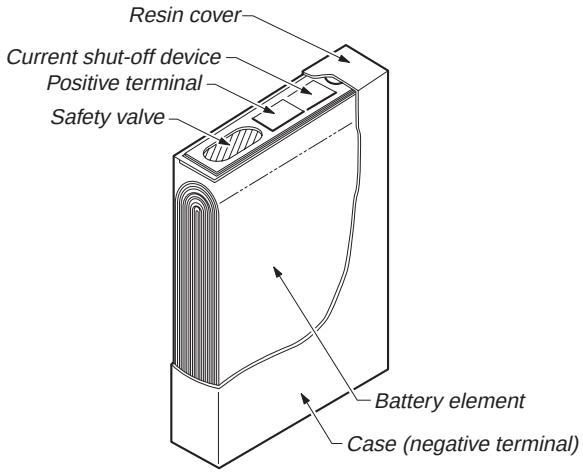



Fig. 5-23 Structure of square lithium-ion secondary battery

Performances of the typical square lithium-ion secondary battery are shown in Table 5-3. The main applications are the portable electronic equipment requiring the compact and thin configuration such as mini-disc, notebook personal computer, etc.

Table 5-3 Performance of square lithium-ion secondary battery

| Model | Nominal voltage [V] | Rated capacity [mAh] | Approximate dimensions [mm] | | | Mass [g] |
|---|---|---|---|---|---|---|
| | | | Width | Thickness | Height | |
| LP4 | 3.6 | 400 | 22 | 6.4 | 47 | 20 |
| LP9 | 3.6 | 800 | 34 | 8.3 | 48 | 40 |

### 3. Battery Characteristics

The cylindrical and square lithium-ion secondary batteries are called cyclic service batteries as they are used in applications in which the charge and discharge cycle is frequently repeated. The cylindrical and square lithium-ion secondary batteries have almost the same battery characteristics. However, the charge/discharge characteristics of the two are slightly different in the type of carbon material that is used for the negative electrode. Figure 5-24 shows difference in the discharge characteristics of batteries having the different types of carbon material for the negative electrode. The graphite negative electrode means carbon materials having high crystallization such as natural graphite and artificial graphite. This battery is characterized by very flat discharge voltage characteristics. In Fig. 5-24, the low crystalline carbon negative electrode indicates the use of carbon materials having low crystallization. Because the discharge voltage changes linearly in proportion to the amount of discharge, the residual power of the battery capacity can easily be displayed.

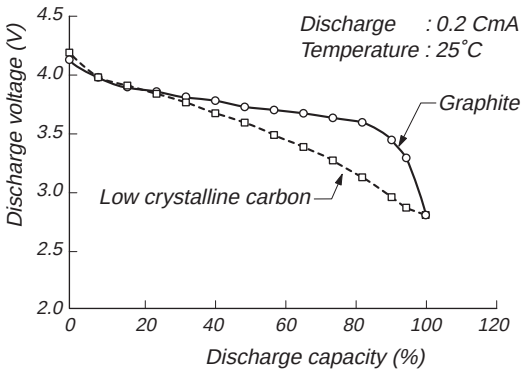



Fig. 5-24 Discharge characteristics of batteries using different materials for negative electrode

The performance of square batteries using graphite carbon materials for their negative electrode are described below.

#### (1) Charge characteristics

The charge characteristics are shown in Fig. 5-25. Because the characteristics of lithium-ion secondary batteries severely deteriorate and safety is impaired if they are charged at higher than the rated voltage, a charging device offering both constant current and constant voltage charging methods with a restricted, specified maximum voltage is required. In the constant current charging zone, the battery voltage increases as the battery is charged. When the battery voltage reaches the set voltage, the charging method is switched to the constant voltage charging. When the battery is charged by the constant voltage method, the charging current gradually decreases until the charging is complete. Some types of batteries can be charged quickly in one or two hours.

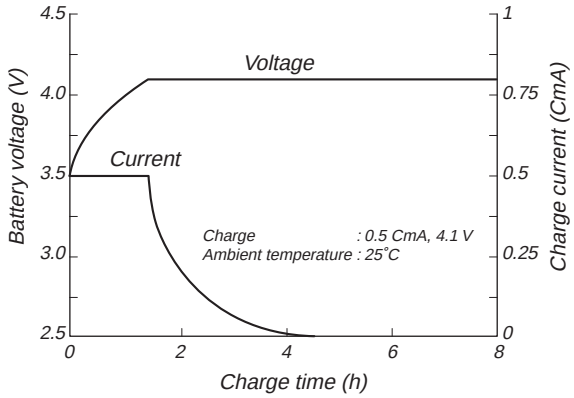



Fig. 5-25 Charge characteristics of square lithium-ion secondary battery

**(2) Discharge characteristics**

The discharge characteristics of various discharge currents are shown in Fig. 5-26. The lithium-ion secondary battery can carry a large discharge current of up to 2 CmA with a reasonably flat discharge voltage as shown in the figure.

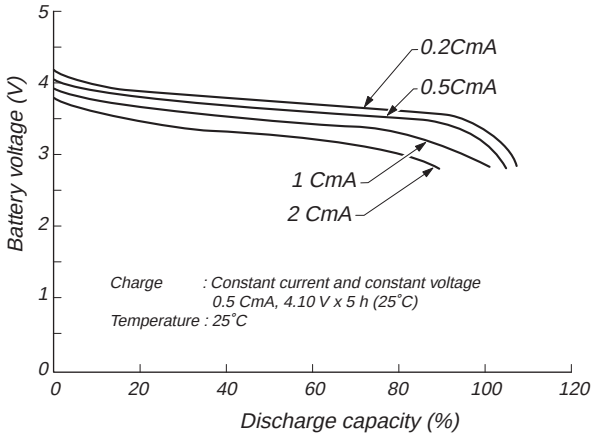



Fig. 5-26 Discharge characteristics of the square lithium-ion battery at various discharge currents

**(3) Temperature characteristics**

The discharge characteristics at various temperatures with 0.2 CmA are shown in Fig. 5-27. The lithium-ion secondary battery can provide a discharge capacity of 90% or more at the low temperature of 0˚C as shown in the figure.

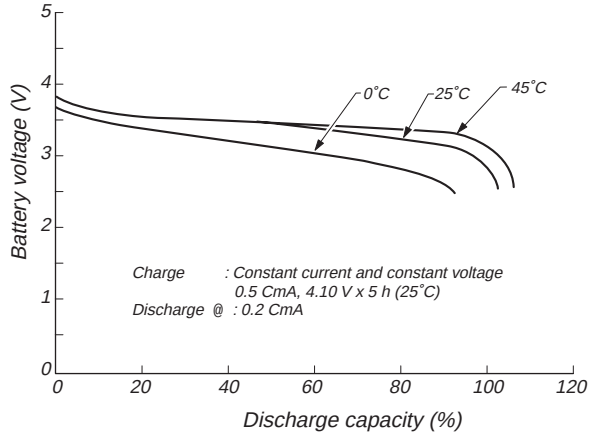



Fig. 5-27 Discharge characteristics of the square lithium-ion battery at different temperatures

### (4) Storage characteristics

The storage characteristics of the lithium-ion secondary battery are shown in Fig. 5-28. The capacity decrease during the initial period is somewhat large as shown in the figure. However, the rate of capacity decrease tends to become small with the elapse of storage days. The storage characteristics of the lithium-ion secondary battery are superior to those of the nickel-cadmium rechargeable battery and the nickel hydrogen rechargeable battery.

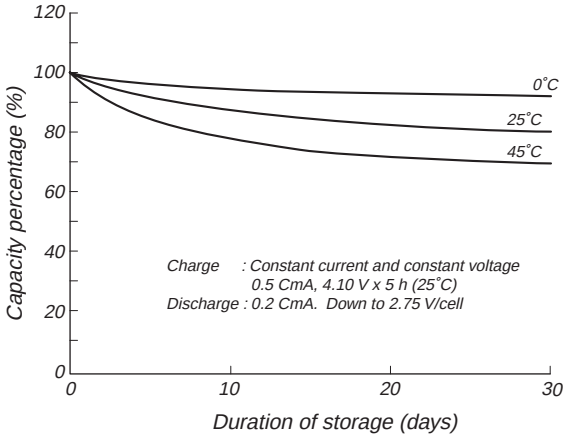



Fig. 5-28 Capacity storage characteristics of the square lithium-ion secondary battery

### (5) Cycle life characteristics

The cycle life characteristics of the lithium-ion secondary battery are shown in Fig. 5-29. The lithium-ion secondary battery delivers a charge/discharge cyclic performance of 500 cycles or more as shown in the figure.

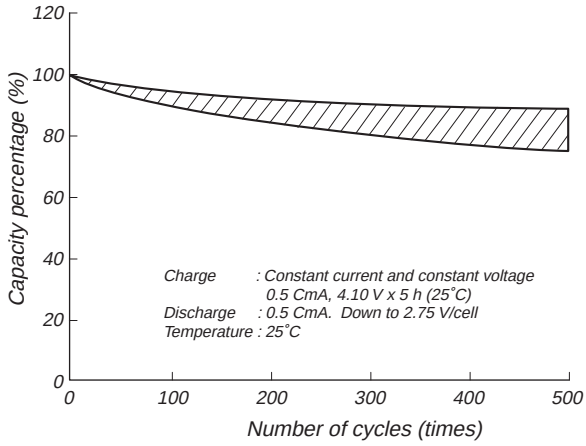



Fig. 5-29 Cycle life characteristics of the square lithium-ion secondary battery

### 4. Charge Method

The lithium-ion secondary batteries must be charged using the charger recommended by the battery manufacturer or with the charging method specified by the battery manufacturer within the specified temperature range (+5 to +45˚C). If the specified charging conditions are not observed, the batteries will not deliver their full performance and their life may be shortened, or abnormal heating or even explosion or fire could occur. The lithium-ion secondary battery has a large energy itself. The components of the battery such as electrolyte and negative electrode are made of inflammable material, and so an excessive charging voltage and excessive charging current severely stress the batteries and can cause explosion or fire. If the lithium-ion secondary batteries are charged with another type of charger that does not satisfy the specified charging conditions, the batteries may not be fully charged, the metallic lithium may be precipitated and cause safety problems, or the electrolyte may cause electrolysis and generate gas so that the safety valve operates. Utmost care is required if the batteries are not to become inoperable.

The cylindrical and square lithium-ion secondary batteries are charged using the constant current and constant voltage charge method. In this method, a battery is charged up to a set voltage (4.1 V or 4.2 V, for example) at a constant current (constant current of 0.5 CmA per 2 hours). When the battery voltage reaches the set voltage, charging is continued at a constant voltage. When the charge method is switched to the constant voltage charging, the charging current gradually decreases and becomes almost zero when the battery is fully charged. Thus, the charging operation ends automatically, and over-charging of a battery is prevented.

### 5. Precautions When Using Lithium-Ion Secondary Batteries

Lithium-ion secondary batteries have a high energy density and are expected to be used in a wide range applications because of their superior characteristics. However, improper handling can cause danger so much more handling care is needed than with conventional secondary batteries.

#### (a) Prevent batteries from shorting

If the positive and negative terminals are shorted, the battery will heat up and could cause an explosion and fire. Batteries may be shorted accidentally if they are transported together with metallic necklaces or hair-pins, for example. Shorting between the battery terminals must be prevented by storing the batteries in special cases or soft cases when transporting them.

#### (b) Do not disassemble the batteries and do not deform the battery case

The organic solvents that constitute the organic electrolyte are inflammable and have an irritant smell. The lithium chloride solute is strongly corrosive against metals so leakage of the electrolyte must be avoided. Because the negative electrode generates hydrogen and causes heating or even fire when reacted with water, disassembling that exposes the inside of the battery or deformation of the battery enclosure is dangerous. Do not damage the batteries such as striking a nail into them, hitting the batteries with a hammer or crushing them.

#### (c) Do not throw into fire, do not place in abnormal heat, and do not heat them

The batteries are housed in a sealed structure. If they are placed in abnormal heat or thrown into a fire, inflammable gas or vapor will be ejected from the safety valve, and hence the enclosure may break, the battery ignite, or some other danger may occur.

#### (d) Do no solder directly to the batteries

Doing so will heat the batteries to a dangerously high temperature.

**(e) Prevent the batteries from coming into contact with water or getting wet**

Be careful not to let the batteries get wet with water or sea water. The lithium-ion secondary batteries have a high electromotive power, and when placed in water, electric current continues to flow, electrolyzing the surrounding water and hence corroding the battery enclosure and terminals. Such battery damage shortens the life of the battery.

**(f) Do not connect the batteries in reverse polarity**

As with other types of battery, connecting batteries in reverse polarity may damage equipment during operation, damage the battery, or cause a fire during charging.

**(g) Do not discharge at a current larger than the specified value**

If batteries are discharged at a current larger than the specified value, the batteries will become abnormally hot and deteriorate irrecoverably, or the batteries may become inoperable if the safety valve is triggered.

**(h) Do not charge at a current larger than the specified value**

If batteries are charged at a current larger than the specified value, the batteries will become abnormally hot and battery life will be adversely affected. At the same time, electrolyte will be dissolved and generate gas or metal lithium, causing internal shorting. Therefore, be sure to use the special charger to charge the batteries.

**(i) Do not over-charge batteries**

If batteries are charged exceeding the specified upper limit voltage, electrolyte will be dissolved and generate gas or metal lithium will be generated that causes internal shorting. Over-charging will remarkably degrade the battery characteristics or make batteries inoperable if the safety valve is triggered. If batteries are severely over-charged, the batteries may even explode or ignite.

**(j) Do not over-discharge**

If batteries are over-discharged exceeding the charge end voltage, the electrodes may deteriorate irrecoverably, or electrolyte may be dissolved. This can cause the collector or internal leads to melt, adversely affecting the performance and causing poor contact.

**(k) Do not disassemble the battery pack or modify it**

The battery pack has a built-in protection circuit to prevent danger. If the protection circuit is disconnected or damaged when disassembled or modified, it will not function in case of emergency, and so heating and damage to the batteries may occur. Never disassemble or modify the batteries.

9-924-949-31

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98H1630-1D
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